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# PLANT AND SOIL

International Journal of Plant Nutrition, Plant Chemistry, Soil Microbiology and Soil-borne Plant Diseases

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# PLANT AND SOIL

**International Journal of Plant Nutrition, Plant Chemistry, Soil Microbiology and Soil-borne Plant Diseases**

**Revue internationale de nutrition des plantes, de chimie végétale, de microbiologie du sol et des maladies des plantes en rapport avec le sol**

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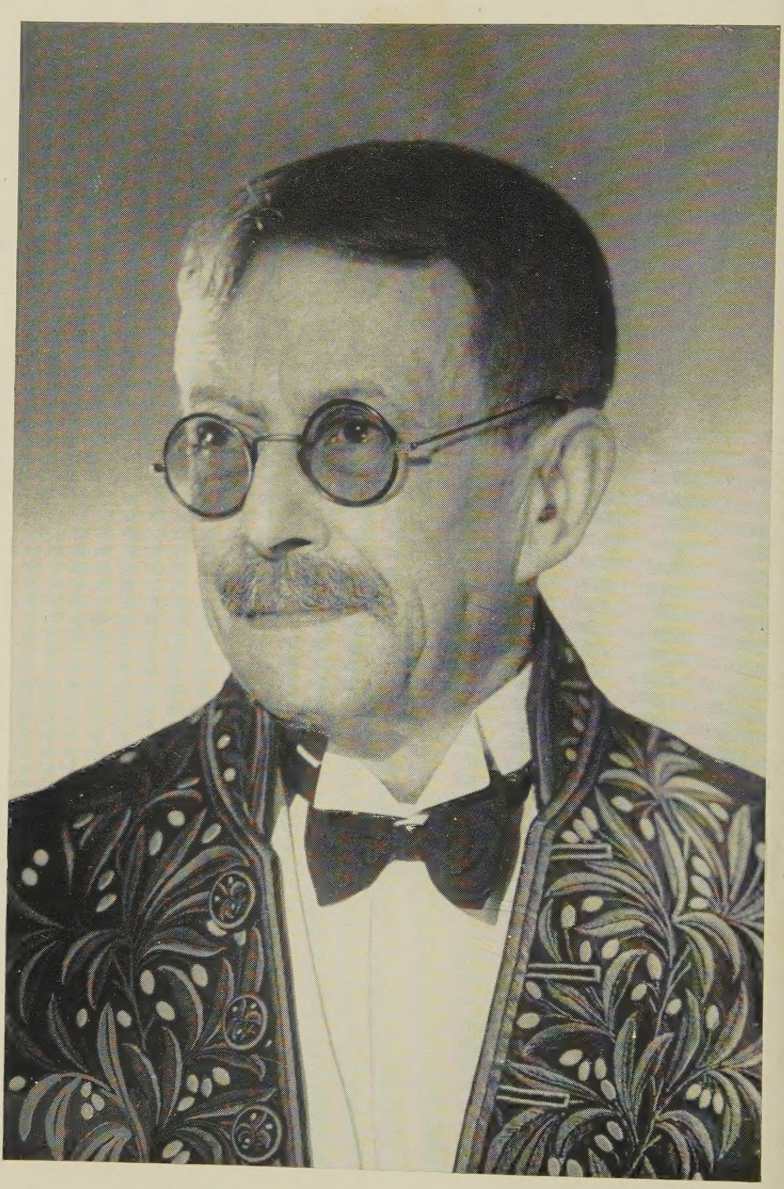

ALBERT DEMOLON 1881—1954

# ALBERT DEMOLON 1881–1954

Albert Demolon, né à Lille en 1881 est mort à Paris le 23 Octobre 1954. Il était Ingénieur-Agronome (1901), licencié et Docteur ès-Sciences (1926). Nommé, en 1909, Directeur de la Station Agronomique de l'Aisne et du Laboratoire Départemental de Bactériologie à Laon, il demeura dans ces fonctions pendant dix-sept années puis il fut nommé Inspecteur Général des Stations et Laboratoires au Ministère de l'Agriculture. Son oeuvre de chercheur et de chef d'Ecole prit alors un développement considérable.

En 1930–31 il avait supplé A. Th. Schloesing dans la Chaire de Chimie Agricole du Conservatoire National des Arts et Métiers qui, sous le nouveau titre de Chimie Agricole et Biologique, eut ensuite comme titulaire M. Javillier. A partir de 1940, Demolon dirigea le Centre de Recherches Agronomiques de Versailles. Il devint, de 1941 à 1950, Professeur de Pédologie et Physique du Sol à l'Ecole du Génie Rural.

Albert Demolon prit sa retraite officielle en 1946, mais son activité continua de s'exercer, en qualité de Conseiller Scientifique dans l'Industrie des Engrais, jusqu'à sa mort. Toute sa carrière, comme il l'écrivit lui-même, „s'est donc déroulée entièrement au laboratoire en contact étroit avec l'agriculture et à son service". Elu Membre de l'Académie des Sciences en 1946, il appartenait depuis 1934 à l'Académie d'Agriculture. Demolon avait eu l'occasion de présider plusieurs sociétés telles que l'International Society of Soil Science, l'Académie d'Agriculture de France, l'Association française pour l'Etude du Sol. Il était Membre Associé de l'Académie d'Agriculture de TchécoSlovaquie et de l'Académie Royale d'Agriculture de Suède. Il était aussi Consulting Editor de la Revue „Plant and Soil."

Si la personnalité du Savant que fut Albert Demolon est connue [1]) de tous les agronomes et, généralement des travailleurs scientifiques qui s'intéressent au sol et à la nutrition des végétaux cultivés, comme à la microbiologie agricole, il est intéressant de rappeler quelles furent les „idées directrices" qui ont inspiré son oeuvre. Celles-ci ont été exposées par lui-même et mieux vaut les reproduire textuellement que les paraphraser. Le style de Demolon se montre à cette occasion caractéristique de la clarté d'esprit et de l'originalité du chercheur.

„Nous avons abordé la recherche agronomique à une époque où la plupart des problèmes de l'économie rurale étaient envisagés sous un aspect uniquement chimique. Il nous est apparu qu'après la période des résultats heureux correspondant à l'introduction des engrais chimiques, la science agronomique était arrivée à un état de stagnation imputable à *l'insuffisance de nos connaissances générales concernant les rapports de la plante et du sol.* [2])

Persuadés qu'il n'y a pas de savoir scientifique sans théorie et que même au point de vue strictement utilitaire la valeur de l'intelligence des phénomènes prime de très haut celle de toutes les connaissances pratiques, nous nous sommes proposés, dans le domaine de la production végétale, de substituer des données scientifiquement établies aux observations empiriques de la pratique agricole .....

Frappés de l'insuffisance des conceptions régnantes qui faisaient du sol un support étudié uniquement à l'état statique par les méthodes de l'analyse minérale, nous en avons poursuivi l'étude dans des conditions nouvelles, plus adéquates à son caractère de milieu naturel en tenant compte des vues nouvelles introduites par les pédologues russes .....

La minéralogie, la chimie, la physico-chimie, la microbiologie, sont également indispensables à la recherche agronomique et l'agronome qui se priverait aujourd'hui de la possibilité de choisir dans cet ensemble de ressources que peut lui apporter

[1]) Voir, par exemple, les notices biographiques publiées par:
M. Jayillier, Compt. Rend. **239**, 1165–70 (1954).
Lemoigne, Compt. Rend. Acad. Agr. **40**, 622–4 (1954).
R. K. Schofield, Nature **174**, 1171 (1954).

[2]) Cette partie du texte n'était pas imprimée en italique dans sa rédaction originale.

la science actuelle, verrait se restreindre considérablement la portée de ses efforts ainsi limités à des abstractions de phénomènes et à des vérités partielles. .....

Nous nous sommes inspirés dans la recherche agronomique des principes mêmes posés par C l a u d e B e r n a r d dans son „Introduction à l'Etude de la Médecine Expérimentale"; il existe en effet, à notre avis, une analogie profonde entre ces deux domaines de connaissance qui puisent leurs bases dans la méthode expérimentale et qui évoluent progressivement du stade conjectural à celui de discipline scientifique. .....

..... Nous avons toujours rapproché des études de laboratoire l'expérimentation au champ, nécessaire à l'obtention de conclusions ayant une valeur pour l'agriculture. Les règles à observer en la matière ont été précisées et codifiées. L'organisation systématique de ces expériences dans le réseau des Stations Agronomiques a permis d'établir des principes susceptibles d'utilisation en Agriculture.

Etudes de laboratoire, essais en vases, expérimentation au champ, tels sont, en définitive, les trois aspects de la recherche agronomique telle que nous l'avons poursuivie depuis 1925. Elle associe toujours étroitement la plante et le sol et vise moins à accumuler un grand nombre d'observations souvent disparates ou contradictoires, que de donner aux expériences le maximum de précision".

L'oeuvre d'A l b e r t D e m o l o n est trop vaste pour être résumée. Ses travaux scientifiques, nombreux et variés, sont tous consacrés soit à l'étude des sols, soit aux rapports des sols et des cultures. Les recherches qu'il poursuivit avec B a s t i s s e sur l'altération du granite en case lysimétrique ont montré qu'en cinq ans, sous l'influence des facteurs climatiques, se produisait une séparation à peu près totale des espèces minérales; mais que, par contre, les processus de solubilisation et d'hydrolyse étaient très réduits. Une petite quantité seulement d'argile colloïdale était produite.

L'importance des complexes ferrisiliciques dans les phénomènes de migration du fer a été démontrée par D e m o l o n et B a s t i s s e. Ces complexes constituent une source de fer utilisable par les plantes: leur application a permis de remédier à la carence en fer de la vigne et des arbres fruitiers en sols calcaires.

D e m o l o n étudia la transformation d'un terrain sédimentaire, le loess, en „limons qui couvrent de vastes surfaces livrées à la culture intensive". Il consacra beaucoup de travaux aux colloïdes du sol, spécialement aux colloïdes argileux. Sa thèse de Doctorat ès-Sciences fut dédiée à des „Recherches physicochimiques sur la terre à briques envisagée comme milieu naturel". Seul, ou avec ses collaborateurs, il apporta une contribution importante aux connaissances sur la constitution des argiles; sur les échanges de cations auxquels elles donnent lieu; sur les complexes argilohumiques et leurs propriétés.

L'influence des anions et des cations sur l'état — dispersé ou floculé — des colloïdes du sol fut analysée par lui avec beaucoup d'habileté dans plusieurs notes ou mémoires.

L'originalité des conceptions de D e m o l o n s'est souvent manifestée. En 1929 il étudia avec B a r b i e r la fixation et la mobilisation de l'acide phosphorique dans les limons, puis il proposa d'apprécier les besoins des sols en acide phosphorique par la détermination de la concentration d'une solution phosphorique qui ne cède ni ne gagne d'acide phosphorique quand on la met en contact avec le sol à analyser (concentration critique d'équilibre). La *constante* ainsi déterminée permet de classer les sols au point de vue de leurs besoins en engrais phosphatés, beaucoup mieux que d'après la *réserve* en $P_2O_5$ mobilisable qui ne suffit pas à caractériser l'*état* du sol.

La microbiologie, „également indispensable à la recherche agronomique et à l'agronomie" prend une place importante dans l'oeuvre de D e m o l o n. Dès 1912 il avait, le premier, signalé l'oxydation biologique à l'état sulfurique du soufre élémentaire introduit dans le sol. Au sujet de la symbiose bactérienne et de la fatigue des sols où se développent des légumineuses, D e m o l o n a montré avec D u n e z que *B. radicicola* manifeste une grande variabilité, non seulement quant à sa „densité" „mais aussi et surtout en ce qui concerne les propriétés physiologiques des individus à l'intérieur d'un même groupe. Cette hétérogénéité est le résultat d'une tendance marquée à la dégénérescence."

„Deux caractères se sont montrés corrélatifs d'une activité fixatrice (d'azote) élevée:

1°) la résistance au bactériophage; 2°) la production de déshydrogénase mesurée par la vitesse de décoloration du bleu de méthylène".

Ces caractères ont permis de sélectionner et contrôler commodé-

ment les souches utilisées pour l'inoculation des graines. L'inoculation réalisée dans les conditions de la pratique suivant les données de Demolon a permis de réussir la culture de la luzerne en de nombreuses régions où cette culture avait dû être abandonnée.

Il serait injuste de ne pas rappeler les travaux de Demolon sur l'analyse de la structure des sols et divers autres aspects de la physique du sol. La plupart de ces travaux ont été réalisés avec son collaborateur S. Hénin.

En raison des fonctions officielles qu'il a rempli, mais surtout par la valeur de son esprit et l'autorité de ses travaux, Albert Demolon a exercé en France une influence considérable sur toutes les recherches agronomiques. Son oeuvre personnelle se double d'un travail collectif, celui qui a été réalisé sous son inspiration par l'ensemble des Stations Agronomiques. Il fut aussi un véritable chef d'Ecole pour ceux qui furent ses collaborateurs et à qui il permit de développer leur personnalité propre. Cette Ecole subsiste.

Ecrivain scientifique aussi précis que largement cultivé, Demolon a publié plusieurs livres. Son Ouvrage fondamental, intitulé *Principes d'Agronomie*; tome I: *La Dynamique du Sol*; tome II: *Croissance des Végétaux cultivés*, a diffusé les acquisitions scientifiques les plus récentes. Ces traités très originaux ont exercé sur la formation des étudiants et sur l'orientation des travailleurs de langue française une influence puissante.

Profondément touché, dès 1950, par la perte accidentelle de Mme Demolon, Albert Demolon, homme de science loyal et savant respecté est mort subitement dans sa soixante-quatorzième année n'ayant pas cessé jusqu'au dernier jour de se consacrer au travail scientifique.

Paris J. Lavollay

Plant and Soil VI, no 3 May 1955

# A PHYSICO-CHEMICAL ANALYSIS OF SALT ACCUMULATION BY PLANT ROOTS

by G. J. VERVELDE

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## 1. INTRODUCTION

Many investigators have recognized the importance of the presence of indiffusible ions in membranes for the migration of mineral and organic ions through the protoplasm. The rôle played by indiffusible ions in the uptake of mineral ions from the external medium has received much attention, as has been described in a previous paper [12]). In the same paper it was stressed that there is no reason to suppose that the presence of these indiffusible ions in living organisms is limited to the surface layer of a tissue. Their presence will thus affect the behaviour of migrating ions in the inner parts of the organism as well as in the peripheral layer.

Theoretical studies of some of the relations between diffusing ions and a membrane containing indiffusible ions have been made by Meyer [7]), Teorell [11]), Briggs and Robertson [1]) and Eriksson [3]). In the present paper special attention will be paid to the rôle played by indiffusible, amphoteric, ionogenic substances in the process of salt accumulation by living organisms. The term salt accumulation will be used to denote the accumulation of both the cations and anions of a salt into one phase of the system. This implies that accumulation of single ions, *e.g.* anions in one phase of the system and cations in another, will not be considered to be salt accumulation.

For the sake of simplicity concentrations will be considered equal to activities.

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*) Now: Ministry of Agriculture, The Hague, the Netherlands.

## 2. MIGRATION OF IONS THROUGH A PHASE CONTAINING AN AMPHOTERIC COLLOID

Imagine a phase filled homogeneously with a hypothetical type of protoplasm which behaves as an amphoteric mixture of acidoids and basoids as described by V e r v e l d e and T e n d e l o o [13]). The excess of either the positive or the negative indiffusible ions is assumed to be a linear function of pH:

$$A = K_1 \log c_H - K_2 \text{ or } A = K_1' \ln c_H - K_2 \qquad (1)$$

The pH value at which the excess of either type of ion becomes zero (*i.e.* when there are equivalent amounts of positive and negative indiffusible ions) will be the isoelectric point (IEP). Although the composition of the amphoteric mixture is itself supposed to be uniform throughout the phase considered, its physico-chemical state may differ from point to point in the phase. Thus differences in reaction (pH) would result in differences in the concentrations of indiffusible ions.

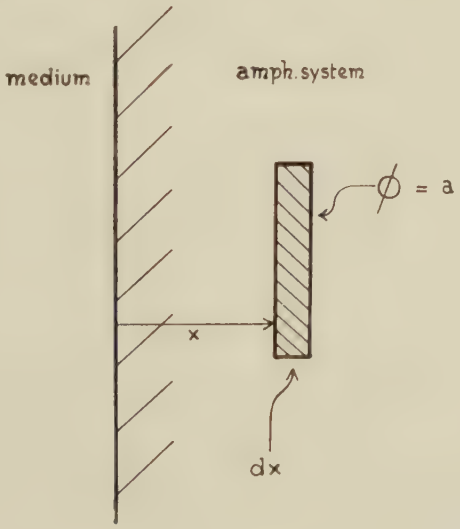


Fig. 1.

Figure 1 shows a cross-section of such a phase in contact with a liquid medium along with a very small volume increment bounded by parallel planes of area $a$ separated by the distance $dx$. The volume

increment is a layer parallel to the boundary between the phase and the liquid medium and at a distance $x$ from the boundary. It will be supposed that protoplasmic streaming does not take place in a direction at right angles to the area $a$ of the volume increment; streaming in a direction parallel to the area $a$ of the volume increment does not invalidate the following considerations.

Migration of diffusible ions in the volume increment can be effected by two kinds of forces: osmotic forces arising from concentration gradients and an electrical force resulting from an electrical potential gradient.

(The possibility that ion transport takes place by means of carrier substances will not be considered here. It is doubtful whether such a carrier substance is available for all kinds of ions. Furthermore a carrier theory does not seem acceptable before it has been demonstrated that such a carrier substance migrates in sufficient amounts and at adequate speed).

Of any gradients existing in the volume increment only the components at right angles to the area $a$ of the volume increment will be considered. If for a given kind of ion the concentration gradient is $dc/dx$ and the electrical potential gradient is $dE/dx$, the migration rate can be expressed by the following formula, derived by Nernst[8]):

for anions

$$\frac{u}{nF}\left(-\frac{RT}{c}\frac{dc}{dx}+nF\frac{dE}{dx}\right) \tag{2}$$

and for cations

$$\frac{u}{nF}\left(-\frac{RT}{c}\frac{dc}{dx}-nF\frac{dE}{dx}\right) \tag{2'}$$

Thus the total amount $S$, displaced through the volume increment in unit time is

$$S_{\mp}=\frac{acu}{nF}\left(-\frac{RT}{c}\frac{dc}{dx}\pm nF\frac{dE}{dx}\right) \tag{3}$$

In this expression

$S_{\mp}$ = moles transported in unit time (the index denoting anions and cations respectively)

$a$ = area

$c$ = concentration in moles

$u$ = migration rate in cm sec in an electrical field with a potential gradient of 1 Volt/cm
$n$ = valency
$R$ = gas constant = 8,316 joule
$T$ = temperature in degrees Kelvin
$F$ = Faraday = 96501 coulombs
$x$ = direction of migration
$E$ = electrical potential in Volts.

For any kind of diffusible ion present in the system, an expression of type (3) can be derived. These equations are not entirely independent because, in a system like this, where no net transport of electricity occurs, the amounts of ions of opposite charge transported must be equivalent. This can be expressed by

$$\Sigma n_+ S_+ = \Sigma n_- S_- \tag{4}$$

If the expressions from equation (3) are substituted in equation (4), the following expression for $dE/dx$ can be derived:

$$\frac{dE}{dx} = \frac{RT}{F} \frac{\Sigma u_- \frac{dc_-}{dx} - \Sigma u_+ \frac{dc_+}{dx}}{\Sigma n_\mp u_\mp c_\mp} \tag{5}$$

It thus appears that the electrical potential gradient at $x$ is entirely determined by the concentrations, concentration gradients and mobilities of the ions present.

By means of equation (5) $dE\ dx$ can be eliminated from equation (3) and the following equation is obtained for the $i$-th cation

$$S_i = \frac{ac_i u_i}{n_i} \frac{RT}{F} \left( -\frac{1}{c_i} \frac{dc_i}{dx} - n_i \frac{\Sigma u_- \frac{dc_-}{dx} - \Sigma u_+ \frac{dc_+}{dx}}{\Sigma n_\mp u_\mp c_\mp} \right) \tag{6}$$

In the case of anions the minus-sign before the second term in brackets becomes a plus-sign.

Equation (6) shows that the amount of a particular kind of ion transported in unit time depends on the following variables:

*a.* the concentration and the concentration gradient of the ion in question,
*b.* the concentrations and the concentration gradients of all the other ions present and

*c.* a number of constants, such as the valencies and the mobilities of the different ions.

If the ionic composition of the system is known at a given moment, that is if the function $c_i = f_i(x)$, giving the relation between the distance ($x$) from the boundary and the concentration, is known for all types of ions present, the concentration gradients $dc_i/dx = f_i'(x)$ are also known. As a result the net transference of ions through any volume increment of thickness $dx$ can be calculated. The result of such a calculation has only a momentary validity because transport of ions may lead to a change in the concentrations and concentration gradients, that is a change in the conditions governing the transport of ions. Thus, for a complete description of the process of ion displacement both the distance ($x$) from the boundary and the time ($t$) must be considered.

If, at a given moment, an amount ($S_t$) of a particular ion moves across the left side of the volume increment (Fig. 1), the amount passing through the right side will be $S_t - (dS/dx)_t dx$. It follows that the volume increment will have its content of the ion in question increased by $-(dS/dx)_t dx$ in unit time. Since the volume is $a\,dx$, the concentration will increase by

$$-\frac{1}{a\,dx}\left(\frac{dS}{dx}\right)_t dx = -\frac{1}{a}\left(\frac{dS}{dx}\right)_t,$$

or written mathematically

$$\left(\frac{dc}{dt}\right)_x = -\frac{1}{a}\left(\frac{dS}{dx}\right)_t \qquad (7)$$

Equation (7) needs modification if combination of ions or dissociation into ions takes place as a consequence of the change in concentration. Such processes must be expected if H-ions or OH-ions migrate into or out of the volume increment because any such changes in concentration are counteracted by the buffering properties of the amphoteric substance. As the H-ions and the indiffusible ions combine or dissociate in equivalent amounts, equation (7) takes the following form for H-ions

$$\left(\frac{dc_H}{dt}\right)_x = -\frac{1}{a}\left(\frac{dS_H}{dx}\right)_t + \left(\frac{dA}{dt}\right)_x \qquad (8)$$

Equation (1) yields, upon differentiation with respect to $x$,

$$\left(\frac{dA}{dt}\right)_x = \frac{K_1'}{c_H}\left(\frac{dc_H}{dt}\right)_x \tag{9}$$

By substitution of equation (9) in equation (8) an expression is obtained for $(dc_H/dt)_x$:

$$\left(\frac{dc_H}{dt}\right)_x = -\frac{1}{a\left(1 - \frac{K_1'}{c_H}\right)}\left(\frac{dS_H}{dx}\right)_t \tag{10}$$

The differential equations (6), (7) and (10) give a complete description of the ionic composition of the hypothetical phase, if it is possible to define the initial state in terms of the function $c_i = f_i(x)$. Although the differential system does not seem to be very complicated, a general solution cannot be given and even a numerical solution is too laborious to be justifiable. In the following sections a few special cases will be examined.

## 3. CONDITIONS FOR SALT ACCUMULATION AGAINST A CONCENTRATION GRADIENT

The formulae for the migration of ions given in the preceding section enable an analysis to be made of the possibilities for accumulation phenomena to occur in an amphoteric system such as is being considered in this paper.

The basis for accumulation of single ions against a concentration gradient can easily be derived from equation (3) by determining the conditions under which $S$ and $dc/dx$ have the same sign. It will be seen that for a given kind of anion $S$ and $dc\ dx$ can both be positive (transport from left to right under the conditions shown in Fig. 1), if $dE\ dx$ is sufficiently positive to give the second term in brackets a positive value exceeding the negative value of the first term. A positive value of $dE\ dx$ may be brought about by a higher concentration of indiffusible positive ions on the right side; the process of accumulation may then be considered as the attraction of negative anions by a high concentration of positive adsorbing groups.

However, the above type of ion accumulation is not salt accumulation proper which has been defined in section 1 as the accumulation of both the anions and the cations of a salt in one phase,

such as happens in the vacuoles and xylem vessels of living plants.

It is not sufficient, apparently, to investigate the behaviour of the concentrations of the anions and the cations separately, especially since these concentrations in those phases containing a certain amount of indiffusible ions are not directly comparable to concentrations in adjacent phases not having indiffusible ions (such as vacuoles and vessels in plants).

For the purpose of examining the possibility of simultaneous accumulation of the cations and anions of a salt it was found very useful to consider the product ($p$) of the concentrations of the cations and anions of a salt (or the concentrations raised to a power corresponding to the number of anions or cations occurring in the salt molecule). One reason is that this product can be used as a direct indication of the accumulation level. If the product at any point in the amphoteric colloid phase is higher than in the external medium one may conclude that accumulation has taken place. The second reason is that, in accordance with the Donnan laws as set out by V e r v e l d e [12]), the product is equal on each side of a boundary separating two phases, one phase having and one phase not having indiffusible ions. Therefore the product ($p$) is not subject to very sudden fluctuations at the boundaries between protoplasm, containing and protoplasm-free phases, as are the concentrations themselves. The accumulation level of a salt in a protoplasm-free phase may simply be derived from the product ($p$) in the adjacent protoplasmic layer. Thus for a theoretical approach to the problem of accumulation only the behaviour of ($p$) in a protoplasm-containing phase needs consideration and calculation of the concentration in a protoplasm-free phase from those in the protoplasm-containing phase can be dispensed with.

For an analysis of the conditions for salt accumulation reference will be made to the system shown in Fig. 1. What conditions will 1. give the concentration product ($p$) in the volume increment ($dx$) a positive gradient (increasing from left to right) and 2. cause an increase in the value of $p$ with time?

For a given salt, consisting of anions with valency $n_a$ and cations with valency $n_k$, the product of ion concentrations is $(c_a)^{n_k} \times (c_k)^{n_a}$ and the first accumulation condition can be written:

$$\frac{dp}{dx} = \frac{d\{(c_a)^{n_k} \times (c_k)^{n_a}\}}{dx} > 0.$$

This expression can be elaborated:

$$\frac{dp}{dx} = (c_a)^{n_k} \times n_a (c_k)^{(n_a - 1)} \frac{dc_k}{dx} + (c_k)^{n_a} \times n_k (c_a)^{(n_k - 1)} \frac{dc_a}{dx} \qquad (11)$$

From equation (3) it follows

$$\frac{dc_a}{dx} = \frac{\dfrac{-n_a S_a}{ac_a u_a} + n_a \dfrac{dE}{dx}}{\dfrac{RT}{c_a F}} \quad \text{and} \quad \frac{dc_k}{dx} = \frac{\dfrac{-n_k S_k}{ac_k u_k} - n_k \dfrac{dE}{dx}}{\dfrac{RT}{c_k F}} \qquad (12)$$

By substitution in equation (11) we get

$$\frac{dp}{dx} = n_a (c_a)^{n_k} (c_k)^{(n_a - 1)} \frac{\dfrac{-n_k S_k}{ac_k u_k} - n_k \dfrac{dE}{dx}}{\dfrac{RT}{c_k F}} + n_k (c_k)^{n_a} (c_a)^{(n_k - 1)} \frac{\dfrac{-n_a S_a}{ac_a u_a} + n_a \dfrac{dE}{dx}}{\dfrac{RT}{c_a F}}$$

or

$$\frac{dp}{dx} = \frac{F}{RT} \left\{ - n_a (c_a)^{n_k} (c_k)^{n_a} \frac{n_k S_k}{ac_k u_k} - n_a (c_a)^{n_k} (c_k)^{n_a} (n_k) \frac{dE}{dx} - \right.$$

$$\left. - n_k (c_k)^{n_a} (c_a)^{n_k} \frac{n_a S_a}{ac_a u_a} + n_k (c_k)^{n_a} (c_a)^{n_k} (n_a) \frac{dE}{dx} \right\}.$$

As the second and fourth term on the right are identical, but have opposite signs, they may be neglected so that finally

$$\frac{dp}{dx} = \frac{F}{RT} \frac{n_a n_k (c_a)^{n_k} (c_k)^{n_a}}{a} \left\{ - \frac{S_k}{c_k u_k} - \frac{S_a}{c_a u_a} \right\} \qquad (13)$$

The sign of this expression depends only on the signs of $S_k$ and $S_a$, as all the other terms appearing in the expression are positive. Obviously, for $dp/dx$ to be positive there are the following possibilities:

*a.* $S_k < 0$ and $S_a < 0$, that is, in the system shown in Fig. 1, there is an outward migration of both the cations and anions. Under

these conditions the very opposite of salt accumulation takes place.

*b*1. $S_k \geqq 0$ and $S_a$ sufficiently negative to make $dp/dx$ positive.

*b*2. $S_a \geqq 0$ and $S_k$ sufficiently negative to make $dp/dx$ positive.

As no other possibilities are available, the inevitable conclusion is that the condition $dp/dx > 0$ can only be satisfied if one of the ions moves outwards. As the nature of the accumulating system does not in any way affect the validity of equation (*13*), the conclusion reached can be laid down in the following rule:

*Salt accumulation requires an outward migration of either the cations or the anions of the salt irrespective of the nature of the accumulating system.*

Obviously, if during salt accumulation one kind of ion moves outwards there must previously have been a stage in which these ions had the opportunity to move inwards. One hypothesis to explain these two stages of salt accumulation will be subjected to a mathematical test in the next section.

## 4. SALT ACCUMULATION UNDER THE INFLUENCE OF A $c_H$ GRADIENT

There are several reasons to suppose that it is the anions that are moving outwards during the second stage of salt accumulation in living plants. These anions thus fulfill the conditions necessary for accumulation. These anions must have moved inwards in an earlier stage, and the hypothesis is put forward here that the inward migration of anions has taken place under the agency of a high concentration of hydrogen ions (low pH) in the interior of the system. (This low pH in the living system must have been brought about by active metabolic processes). It is supposed that in a later stage the hydrogen ion concentration would decrease. This would give rise to an increasing concentration of negative indiffusible ions with the result that cations would be required to neutralize these indiffusible anions, whilst diffusible anions would move outwards due to the tendency of any system containing indiffusible negative ions to expell the diffusible anions. Thus the diffusible cations and anions would move in opposite directions thereby fulfilling the essential conditions for salt accumulation.

Only the physico-chemical implications of the above hypothesis will be examined in the following section.

In order to test the hypothesis just described it will be demonstrated that a high $c_H$ in the interior of an amphoteric system (a positive $c_H$ gradient) could bring about salt accumulation if the hydrogen ion concentration decreases. Therefore the behaviour of the product ($p$) of ion concentrations for one salt at a certain position ($x$) (Fig. 1) will be analysed. It is supposed that the hydrogen ions would be removed by a process of diffusion. It is sufficient to prove that by this mechanism the product ($p$) at $x$ can be raised above the corresponding product in the medium, or, what amounts to the same thing, above the product just inside the boundary.

To avoid the complications of solving the complete system of differential equations mentioned at the end of section 2, a few simplifying suppositions are made. Firstly, it is supposed that the amphoteric system, obeying equation (1) regarding the relation between the concentration of indiffusible ions and reaction (pH), contains only $H^+$, $K^+$ and $Cl^-$ as diffusible ions. Secondly, we assume the product ($p = c_K \times c_{Cl}$) to have the same value throughout the system, including the medium. Under these conditions $dp/dx = 0$, and to demonstrate that accumulation is taking place, it is sufficient to prove that $dp/dt$ is positive.

We have

$$\left(\frac{dp}{dt}\right)_x = \left\{\frac{d(c_K c_{Cl})}{dt}\right\}_x = c_{Cl}\left(\frac{dc_K}{dt}\right)_x + c_K\left(\frac{dc_{Cl}}{dt}\right)_x \qquad (14)$$

From (7) it follows

$$\left(\frac{dp}{dt}\right)_x = -\frac{1}{a}c_{Cl}\left(\frac{dS_K}{dx}\right)_t - \frac{1}{a}c_K\left(\frac{dS_{Cl}}{dx}\right)_t \qquad (15)$$

The differentials on the right may be replaced by the results of differentiation of equation (3) with respect to $x$ ($n$ may be omitted as both $K^+$ and $Cl^-$ are univalent):

$$\frac{dS_K}{dx} = -au_K\frac{RT}{F}\frac{d^2c_K}{dx^2} - au_K\frac{dc_K}{dx}\frac{dE}{dx} - au_K c_K\frac{d^2E}{dx^2} \qquad (16)$$

and

$$\frac{dS_{Cl}}{dx} = -au_{Cl}\frac{RT}{F}\frac{d^2c_{Cl}}{dx^2} + au_{Cl}\frac{dc_{Cl}}{dx}\frac{dE}{dx} + au_{Cl}c_{Cl}\frac{d^2E}{dx^2} \qquad (16')$$

These expressions can be substituted in equation (15), and as the

subscripts x and t may be safely omitted, we get

$$\frac{dp}{dt} = c_{Cl}\, u_K \frac{RT}{F}\frac{d^2c_K}{dx^2} + c_{Cl}\, u_K \frac{dc_K}{dx}\frac{dE}{dx} + c_{Cl}\, u_K\, c_K \frac{d^2E}{dx^2} +$$

$$+ c_K\, u_{Cl} \frac{RT}{F}\frac{d^2c_{Cl}}{dx^2} - c_K\, u_{Cl} \frac{dc_{Cl}}{dx}\frac{dE}{dx} - c_K\, u_{Cl}\, c_{Cl} \frac{d^2E}{dx^2} \quad (17)$$

As the mobilities of $K^+$ and $Cl^-$ are approximately equal, we may write $u_K = u_{Cl} = u_{KCl}$, so that equation (17) can be reduced to

$$\frac{dp}{dt} = \frac{RT}{F} u_{KCl}\left(c_{Cl}\frac{d^2c_K}{dx^2} + c_K\frac{d^2c_{Cl}}{dx^2}\right) + u_{KCl}\left(c_{Cl}\frac{dc_K}{dx} - c_K\frac{dc_{Cl}}{dx}\right)\frac{dE}{dx} \quad (18)$$

A further reduction of the first term within brackets may be obtained as follows. Since it was supposed that $dp/dx = 0$, we also have $d^2p/dx^2 = 0$. Hence

$$\frac{d^2p}{dx^2} = \frac{d^2(c_K\, c_{Cl})}{dx^2} = c_{Cl}\frac{d^2c_K}{dx^2} + 2\frac{dc_K}{dx}\frac{dc_{Cl}}{dx} + c_K\frac{d^2c_{Cl}}{dx^2} = 0$$

so that

$$c_{Cl}\frac{d^2c_K}{dx^2} + c_K\frac{d^2c_{Cl}}{dx^2} = -2\frac{dc_K}{dx}\frac{dc_{Cl}}{dx} \quad (19)$$

Equation (18) may now be written

$$\frac{dp}{dt} = -2\frac{RT}{F} u_{KCl}\frac{dc_K}{dx}\frac{dc_{Cl}}{dx} + u_{KCl}\left(c_{Cl}\frac{dc_K}{dx} - c_K\frac{dc_{Cl}}{dx}\right)\frac{dE}{dx} \quad (20)$$

For the system under consideration $dE/dx$ can be derived from equation (5):

$$\frac{dE}{dx} = \frac{RT}{F}\frac{\left(u_{KCl}\frac{dc_{Cl}}{dx} - u_{KCl}\frac{dc_K}{dx} - u_H\frac{dc_H}{dx}\right)}{(u_{KCl}\, c_{Cl} + u_{KCl}\, c_K + u_H\, c_H)}$$

so that equation (20) can now be written

$$\frac{dp}{dt} = \frac{RT}{F} u_{KCl}\left\{-2\frac{dc_K}{dx}\frac{dc_{Cl}}{dx} + \right.$$

$$\left. + \left(c_{Cl}\frac{dc_K}{dx} - c_K\frac{dc_{Cl}}{dx}\right)\left(\frac{u_{KCl}\frac{dc_{Cl}}{dx} - u_{KCl}\frac{dc_K}{dx} - u_H\frac{dc_H}{dx}}{u_{KCl}\, c_{Cl} + u_{KCl}\, c_K + u_H\, c_H}\right)\right\} \quad (21)$$

To eliminate the differentials $dc_{Cl}\,dx$ and $dc_K/dx$, the following relation expressing the electrostatic neutrality of the system may be used:

$$c_K + c_H = c_{Cl} + A \tag{22}$$

By differentiation we obtain

$$\frac{dc_K}{dx} + \frac{dc_H}{dx} = \frac{dc_{Cl}}{dx} + \frac{dA}{dx} \tag{23}$$

Moreover, since $p = c_K \times c_{Cl}$ and $dp/dx = 0$, we have

$$\frac{dp}{dx} = c_K \frac{dc_{Cl}}{dx} + c_{Cl} \frac{dc_K}{dx} = 0 \tag{24}$$

Also, equation (1) leads to

$$\frac{dA}{dx} = \frac{K_1'}{c_H} \frac{dc_H}{dx} \tag{25}$$

From the equations (23), (24), and (25) it follows that

$$\frac{dc_{Cl}}{dx} = - c_{Cl} \frac{\left(\frac{K_1'}{c_H} - 1\right) \frac{dc_H}{dx}}{c_{Cl} + c_K} \tag{26}$$

and

$$\frac{dc_K}{dx} = c_K \frac{\left(\frac{K_1'}{c_H} - 1\right) \frac{dc_H}{dx}}{c_{Cl} + c_K} \tag{26'}$$

After substitution in equation (21) and rearranging we obtain

$$\frac{dp}{dt} = 2 \frac{RT}{F} u_{KCl} u_H c_K c_{Cl} \frac{\left(\frac{K_1'}{c_H} - 1\right) (K_1' - c_H - c_K - c_{Cl})}{(c_K + c_{Cl})^2 (u_{KCl} c_{Cl} + u_{KCl} c_K + u_H c_H)} \left(\frac{dc_H}{dx}\right)^2 \tag{27}$$

If, finally, the mobility of the hydrogen ions is equated to 5 times the mobility of the potassium and chlorine ions, equation (27) becomes

$$\frac{dp}{dt} = 10 \frac{RT}{F} u_{KCl} \frac{c_K c_{Cl} \left(\frac{K_1'}{c_H} - 1\right) (K_1' - c_H - c_K - c_{Cl})}{(c_K + c_{Cl})^2 (c_{Cl} + c_K + 5c_H)} \left(\frac{dc_H}{dx}\right)^2 \tag{28}$$

This relation expresses changes in the value of $p$ with time. Since $K_1'$ is negative, $dp/dt$ is obviously positive. Only if $dc_H/dx = 0$ will $dp/dt$ be zero. It may also be noted that the sign of $dc_H/dx$ does not affect the sign of $dp/dt$. Though we assumed $dc_H/dx$ to be positive, a negative value would also lead to salt accumulation. In the latter case cations would be moving outwards and anions would be moving towards the interior of the system. Thus the following rule emerges:

*If in an amphoteric system the product of the $K^+$ and $Cl^-$ concentrations are equal throughout the system and the medium then this product will increase, that is KCl will be accumulated, if there is a pH gradient. If there is no pH gradient accumulation will not take place.*

Since the theoretical analysis just given is valid for any volume increment, the initial accumulation rate in a series of volume increments along the $x$-axis can be obtained as follows.

Equation (*28*) can be simplified since the first part is a constant: $10\,RTu_{KCl}/F = C$. If the values of $K_1'$ and $p$ for the system are given, the second part of equation (*28*) still contains the variables $c_K$, $c_{Cl}$ and $c_H$. The first two of these can be derived from $p$ and $c_H$ from equations (*1*) and (*22*), so that the differential may be written as a function $f(p, c_H)$, giving

$$\frac{dp}{dt} = C\, f(p, c_H) \left(\frac{dc_H}{dx}\right)^2 \qquad (29)$$

Though $dp/dt$ is a very useful indicator of the occurrence of accumulation, it should be remembered that ($p$) does not represent the salt concentration as such, but a product of two concentrations. In the present case this can easily be remedied because, in the protoplasm-free phase, only a small part of the $Cl^-$ would be present as HCl. Thus the concentration of KCl would be approximately $\sqrt{p}$. The initial accumulation rate would therefore be represented by $d\sqrt{p}/dt$; this can easily be derived from $dp/dt$:

$$\frac{d\sqrt{p}}{dt} = \frac{1}{2\sqrt{p}} \frac{dp}{dt} = C \frac{1}{2\sqrt{p}} f(p, c_H) \left(\frac{dc_H}{dx}\right)^2$$

or

$$\frac{d\sqrt{p}}{dt} = C\, f'(p, c_H) \left(\frac{dc_H}{dx}\right)^2 \qquad (30)$$

Some numerical values of the term $f'(p, c_H)$ have been tabulated in

Table I. They were calculated for two systems, characterized by the following buffer functions according to equation (1):

1) $A_1 = 0.05\,\mathrm{pH} - 0.21$ or $A_1 = -0.0217 \ln c_H - 0.21$

2) $A_2 = 0.10\,\mathrm{pH} - 0.42$ or $A_2 = -0.0434 \ln c_H - 0.42$.

Both systems have their IEP at pH 4.2.

TABLE I

Values of $f'(p, c_H)$ at different pH values

| | | System no. 1 | | System no. 2 | |
|---|---|---|---|---|---|
| | $K'_1 \rightarrow$ | —0,0217 | | —0,0434 | |
| pH | $p \rightarrow$ | $10^{-6}$ | $10^{-4}$ | $10^{-6}$ | $10^{-4}$ |
| 5.2 | | 985 | 8326 | 493 | 4719 |
| 4.8 | | 1305 | 8440 | 655 | 5776 |
| 4.4 | | 8155 | 10707 | 4255 | 17236 |
| 4.3 | | 36942 | 10392 | 21715 | 25328 |
| 4.2 | (= IEP) | 442380 | 8872 | 1690350 | 26927 |
| 4.1 | | 21425 | 6500 | 13070 | 15788 |

It will be observed that $f'(p, c_H)$ attains a maximum near the IEP of the system. At low salt concentrations, that is at low values of $p$, the maximum value of $f'(p, c_H)$ is high. If two systems are compared, the maximum value is highest in the system where $K'_1$ is greatest. As $K'_1$ expresses the buffer capacity of the system it may be concluded that, the $c_H$ gradients being equal, a higher buffer capacity of the system leads to more rapid salt accumulation in volume increments where the pH is at or near the IEP.

The results obtained for individual volume increments may be generalized for a system with a unidirectional $c_H$ gradient. In the top part of Figure 2 variation in $c_H$ in the medium and those at points in the system at increasing distances from the boundary are shown thereby indicating that the $c_H$ gradient is assumed to be linear. In the lower part of Fig. 2, the variation in $\sqrt{p}$ is shown; the initial level of $\sqrt{p}$ is indicated by a continuous line. It is assumed to be the same in all parts of the system. The accumulation rates in various volume increments have been indicated by arrows; these show a maximum accumulation rate near the IEP. The variation in $\sqrt{p}$ at increasing distances $x$ will, after some time, have reached the state indicated by the broken line. Although in the new situation the accumulation rates will not be the same as initially, it will be

demonstrated in the next section that the accumulation will be consistently maximal near the IEP.

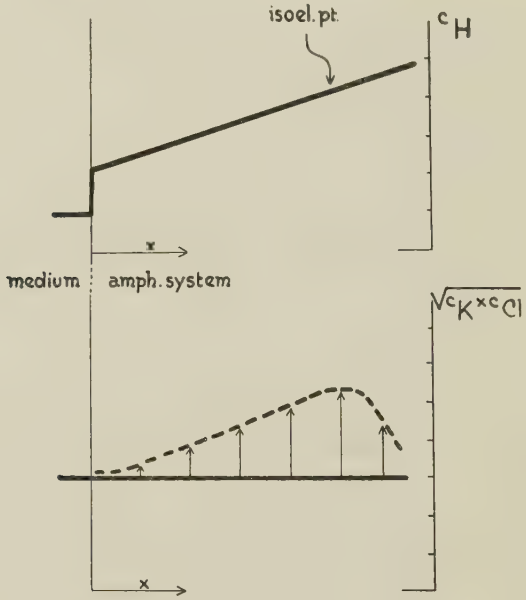


Fig. 2.

## 5. DISCUSSION

The result contained in equation (*13*) is not subject to any restrictions, because there are no underlying assumptions about the nature of the system in which the process of ion migration is supposed to take place. Thus the diffusion of positive and negative ions must be in opposite directions in order that the corresponding salt may be accumulated. The author found no indication in the literature that a similar conclusion has been reached previously. There is only L u n d e g å r d h's [6]) statement, that the accumulation of anions does not take place along the same path as the accumulation of cations.

L u n d e g å r d h does not give any details of the reason for this inference, nor does he discuss the chemical or physical factors underlying the differences in behaviour of both types of "adsorption tracks". In the scheme described in the present paper, any part of the (so far hypothetical) protoplasm could behave as an "adsorption

track" for anions as well as for cations. If the hydrogen ion concentration is increased in the interior of the protoplasmic phase, anions move inwards; if the reverse takes place, cations move inwards. These opposite processes take place at the same point in turn and are thus separated by time and need not, as has been suggested by Lundegårdh, be brought about by a mosaic-like organization of the protoplasm, that is, by a separation in space. Yet, considering some plant organ as a whole there will certainly be special regions where one process or the other prevails.

The apparent necessity for ions of one sign of charge to move outwards during salt accumulation raises the question as to whether such a loss of ions from a tissue has been observed experimentally. Some investigators (Jenny and Overstreet[5], Schuffelen and Loosjes[9]) have observed an outward migration of ions through the root surface. They suggest that, in the case of a net inward transport of ions, there is in addition a thermal diffusion of ions in both directions. The outward component was identified and estimated by the use of labelled ions. It is easily seen that this outward component may partly be due to a local net outward migration of ions which is more than balanced by a net inward migration at other places so that the overall result would still be a net inward migration. Only a very refined technique for measuring the inward and outward flow of ions at different points along the surface of a tissue could settle this question.

Although the mechanism proposed in this paper is still hypothetical, it is interesting to consider some implications. The relation between $K_1$ ($K_1'$), the coefficient expressing the buffer capacity of the adsorbing system and the accumulation rate, raises some instructive points. From equation (*28*) it follows directly that, other conditions being equal, the accumulation rate is greatly influenced by the value of $K_1'$. It is common to find numerical values between 0.026 and 0.012 for $K_1'$ (Verveldе[12]), so that the term $(K_1' c_H - 1)$ is, at normal $c_H$ values, approximately proportional to $K_1'$. In fact the accumulation rate would be negligibly small if $K_1'$ were zero, that is, if the concentration of indiffusible ions were independent of $c_H$. Thus a high value of $K_1'$, that is a high buffering capacity of the adsorbing system, is essential for a high accumulation rate. Contrary to Steward's[10] opinion, the buffering properties of the cell contents do not stand in the way of the hypothesis that

salt accumulation is brought about by a pH gradient. Some previous attempts to explain salt accumulation on a physico-chemical basis might have been more successful if the buffering capacity of the living tissue had not been left out of the picture. Thus a mechanism proposed by Brooks [2], based on a carbonic acid concentration gradient (essentially a pH gradient) was rejected by Teorell [11] because on such a basis, only a very small accumulation rate could be calculated. Some investigators (Meyer [7], Teorell [11], Briggs and Robertson [1]) have been well aware of the variation in concentration of indiffusible ions due to differences in pH, but since no practicable mathematical form was introduced for this relation, the possible connection with salt accumulation remained unexplored.

The mathematical manipulations of the preceding section make it somewhat difficult to acquire a clear view of the fundamentals of the accumulation process described there. It may be useful to provide a simplified though somewhat less accurate picture of the essentials of the theory. Accumulation is thought to be brought about by migration gradients that tend to be smoothed out in such a way that ultimately a uniform electro-chemical potential is reached for each ion. In the case where a $c_H$ gradient is responsible for the migration gradients, as was assumed above, the hydrogen ions and the anions tend to migrate outwards and cations tend to move inwards. At any one point, other conditions being equal, the different ions migrate in amounts which are proportional to their concentrations at that point; this can easily be seen from equation (*13*). In the outer layers of the protoplasmic phase, where the reaction is on the alkaline side of the IEP which results in a surplus of negative indiffusible ions, the concentration of diffusible anions is relatively low, so that there is a correspondingly decreased conductivity for anions. The anions tending to move outwards are held up in the zone of the protoplasmic phase which has a reaction near the IEP. This is due to the sharp decrease in the anion conductivity on the alkaline side of the IEP. Similarly the metal cations moving inwards meet an increased resistance to movement when the reaction is on the acid side of the IEP. The retarding effect of the presence of indiffusible ions on the transfer of oppositely charged diffusible ions has recently been deduced theoretically by Eriksson [3]. The effect is identical

to the well known difference (H ö b e r [4]), p. 317–319)) between negatively charged membranes with a preferential cation permeability.

Thus salt accumulation near the IEP may be considered to be the result of the movement of anions and cations being held up in a zone which has a reaction close to the IEP, when both types of ions are moving in opposite directions. Though this is only a rough picture, it gives confidence that diffusing salts other than KCl will also show a maximal accumulation rate in the zone where the reaction is in the region of the IEP. Whether the maximum accumulation occurs when the reaction is a little on the alkaline or a little on the acid side of the IEP will probably depend on the relative mobilities of the anions and the cations of the respective salts.

## 6. SUMMARY

A theoretical study has been made of migration of ions in a hypothetical protoplasmic system in the form of a phase homogeneously filled with an amphoteric indiffusible substance which represents the protoplasmic contents of living cells. Movement of ions through this substance can be brought about by two kinds of forces: osmotic forces due to concentration gradients and an electrical force resulting from an electrical potential gradient. The latter gradient is not independent, but results from an uneven distribution of ions.

It is shown that the movement of ions through a small volume increment is governed by the concentrations, concentration gradients and mobilities of all kinds of freely diffusible ions present in the volume increment and is expressed by equation (*6*). If the flux of some ion differs on both sides of the volume increment it will be accumulated (*7*). Since H-ions (and also OH-ions) will react with the indiffusible amphoteric substance when their concentration changes a somewhat different relation (equation *10*) is valid for H-ions. The differential system formed by the equations (*6*), (*7*) and (*10*) is used to analyse some special cases of salt accumulation.

In section 3 it is pointed out that accumulation of any salt can best be studied by considering changes in the product ($p$) of the concentrations of cations and anions of the salt. Salt accumulation by a living organ requires that an outward gradient of the product ($p$) be developed or maintained. It s shown that such a gradient is incompatible with simultaneous inward migration of both the anions and the cations of the salt. *The only possible conclusion is that during salt accumulation an outward migration of either the cations or the anions takes place.* A hypothesis is put forward that salt accumulation is brought about by a $c_H$ gradient which decreases gradually (the interior of the system becoming less acid) and causes anions to move outwards and cations to move inwards.

In section 4 a mathematical description is given of the process of salt accumulation in a hypothetical amphoteric system with $H^+$, $K^+$ and $Cl^-$ as diffusible ions and with a linear $c_H$ gradient. If the product ($p$) of the concentration of $K^+$ and $Cl^-$ initially has the same value throughout the system, the initial rate of KCl accumulation at any one place is proportional to the square of the $c_H$ gradient (equations (*28*) and (*29*)) and furthermore is a function of the product ($p$) and of $c_H$ at that place. From Table I it can be seen that for equal $c_H$ gradients the rate of salt accumulation is greater when $p$ is small (in dilute solutions) and is highest where the reaction is near the isoelectric pH. It is probable that other salts (other pairs of ions) will also have a maximum accumulation rate where the reaction approaches the isoelectric pH.

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# INFLUENCE OF SOIL AGGREGATION ON THE ROOTING OF CARNATION CUTTINGS

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## INTRODUCTION

The present paper deals with the formation and growth of adventitious roots in a fine textured soil under various structural conditions No quantitative data on this topic seem to have been published to date.

It was shown in a previous paper [3]) that structure as expressed by size and water stability of aggregates influences considerably the growth of wheat under glasshouse conditions. The formation of roots in carnation cuttings was studied in the present work in a similar structural environment.

Carnations are one of the important florist crops in Israel. They are grown outdoors in a great variety of soils, including nearly all textural groups. They are propagated by cuttings which are generally rooted in a sand-bed. It is generally supposed that the rooting process requires a well-aerated medium.

## MATERIALS AND METHODS

The soil for the experiments was taken from the lands of the settlement Eilon, in the western Galilee hills. Its characteristics have been fully described elsewhere [3]). It is a red heavy clay soil, rich in organic matter and free of calcium carbonate, with a neutral reaction.

Three grades of aggregate sizes were prepared by the following treatments:

*Treatment C, coarse aggregates.* Big clods were broken by hand, stones and straw being discarded.

*Treatment M, medium-sized aggregates.* The clods were broken until they passed through a 2-mm screen.

*Treatment F, fine aggregates.* The clods were ground until they passed through a 0.5-mm screen.

It is assumed that the changes induced by treatments influenced only physical characteristics of the soils, since chemically the soils in the three treatments were identical, at least at the beginning of the experiment, as already shown [3]).

The physical properties of the treated soils where examined by methods described elsewhere [3]), and are detailed in Table I.

TABLE I

| Some physical properties of soils after treatment | | | | | | | |
|---|---|---|---|---|---|---|---|
| Treatment | Size of aggregates, % | | Field capacity, % | Apparent density | Real specific gravity | Pore space, % | Non capillary porosity, % |
| | >1 mm | >0.25 mm | | | | | |
| *C* (coarse) | 88.2 | 92.9 | 31 | 0.96 | 2.36 | 59 | 36 |
| *M* (medium) | 35.1 | 61.3 | 36 | 1.13 | 2.36 | 52 | 23 |
| *F* (fine) | 3.4 | 32.6 | 37 | 1.15 | 2.36 | 51 | 21 |

It is clear that the treatments induced considerable changes in the aggregate sizes of the samples. The data suggest that no appreciable changes in total porosity were produced by the treatments; in the medium sized and fine samples they are actually identical. However, a shift in the pore size distribution is apparent, the coarse aggregate sample containing relatively more large pores than both others.

Porous clay pots, with a top diameter of about 12 cm were filled with 500 to 600 g of soil of treatments *C*, *M* and *F*. Ten pots of each treatment were randomly allotted to 4 blocks in a greenhouse, the whole experiment consisting of 120 pots; into each pot five carnation cuttings were planted. The variety used was "Yavneh red" (a local selection from a Chabaud type) which is widely grown in Israel. Fairly uniform cuttings were dipped for 20 hours in an aqueous solution of 50 ppm indole butyric acid previous to planting on January 11, 1954. The cuttings were given the usual care and irrigated two to three times per week. Each time the soil was brought to field capacity by water addition according to need as determined by loss of weight. At different dates samples were taken to assess root formation, growth and degree of wilting of cuttings. Sections from preserved material were also cut with a serial microtome. On February 21st, and on March 11th cuttings from 12 pots of each treatment were carefully washed free of soil, roots detached at their bases and organic matter of the roots determined.

## RESULTS AND CONCLUSIONS

A representative sample of cuttings (one pot per treatment from each block) examined on January 26th (two weeks after planting) failed to show any macroscopical differences. Stained sections

showed that root initials were present already in the basal callus of cuttings from all soil treatments. No differences in development of the initials or in their number could be detected.

On February 1st in a similar sample of cuttings a certain amount of callus and a few roots beginning to protrude could be seen by the naked eye, as could be expected three weeks after planting. Individual cuttings were graded by means of a four point scale according to the amount of callus and roots observed (0 = no callus; 4 = callus abundant with some roots already visible). In treatment *C*, higher grades were recorded than in treatments *M* and *F*; an analysis of variance failed however to confirm these differences as significant (Table II).

On February 9th another sample was examined. A much more advanced stage of rooting was found and accordingly cuttings were graded on the basis of a six point scale (0 = no callus; 6 = callus abundant with a well-developed root system). Cuttings grown in *C* and *F* treatments were significantly more advanced in rooting than those grown in the *M* treatment. The same trend was seen in a sample taken of February 15th although the threshold of significance was not attained, possibly due to gradual levelling up of differences. On February 9th and 15th cuttings were also graded according to their degree of wilting (0 = fully wilted; 3 = fully turgescent).

TABLE II

Average grades of callus and root development and average degree of wilting of carnation cuttings grown in different soil structures, as assessed at different dates

| Dates | Coarse | Medium | Fine | Significance |
|---|---|---|---|---|
| *a*) Callus and root development | | | | |
| 1.II *) . . . . . | 2.7 | 1.9 | 2.0 | — |
| 9.II §) . . . . . | 4.0 | 1.3 | 4.2 | *C* and *F* vs. *M* ** |
| 15.II §) . . . . . | 3.9 | 2.3 | 3.6 | — |
| *b*) Wilting | | | | |
| 9.II !) . . . . . | 2.85 | 1.45 | 2.70 | *C* and *F* vs. *M* ** |
| 15.II !) . . . . . | 2.75 | 1.58 | 2.30 | — |

*) According to a four point scale.
§) According to a six point scale.
!) According to a three point scale.
**) Significant at the 0.01 level.

The trends of the degree of wilting are in accordance with the trends of the degree of callus and root development. The better

performance of cuttings grown in *F* than in *M* treatments will be explained later.

The average weights of organic matter of roots growing on cuttings uprooted on February 21st and on March 11th are reported in Table III.

TABLE III

Average weights of organic matter of roots detached from cuttings grown in soil of different structures (mg organic matter per 15 cuttings)

| Data | Coarse | Medium | Fine | Significance |
|---|---|---|---|---|
| 21.II . . . . . | 108.0 | 87.0 | 133.3 | — |
| 11.III . . . . . | 392.8 | 209.5 | 268.7 | *C* vs. *M* and *F*** |

**) Significant at the 0.01 level.

Dry weight of roots could not be determined, as we did not succeed in washing the roots completely free of soil. Organic matter values were calculated by difference between dry weight (drying in oven at 80°C overnight) and the remainder after ignition (muffle at about 650°C).

Organic matter values arrived at by this procedure must be somewhat higher than actual values owing to the loss in ignition of the soil particles which remained attached to roots. No adjustment could be made but it is believed that the error involved is not great.

If we assume that the ash content of roots in percentage of dry matter be about 10–15% [5]), the loss in weight of roots due to ignition will be about 85–90% of dry matter. Soil will lose about 10% during the same treatment (loss in organic matter and bound water). Supposing that the dry weight of soil particles be about $\frac{1}{3}$ of the dry weight of roots — a fairly high figure — the error introduced by weight loss of soil through ignition would be about 4%, *i.e.* the value of organic matter found could be higher than actual values by about the same percentual amount.

Moreover considering that we are mainly interested in relative figures, the bias introduced by soil loss of weight through ignition should be very small when comparing different treatments.

At both dates, cuttings growing in the *M* treatment evinced a lower amount of roots than those grown in the *C* treatment. At the first date, results obtained on *F* and *C* treatments were similar (see also Table II). This may be explained by the fact that soil fissures were apparent in the *F* treatment at the point of insertion of the cuttings, some time between irrigations. It may be assumed that

these fissures improved aeration at the base of the cuttings. No fissures were detected in soils of *C* and *M* treatments.

Oxygen diffusion in the different treatments was measured by means of a platinum electrode [4]) in pots of the same size as the experimental pots. The results of these measurements are recorded in Table IV.

TABLE IV

Measurements of oxygen diffusion in pots containing different soil treatments ($10^{-8}$ g/sq. cm/min)

| Treatments | Soil at field capacity (into which the electrode has been introduced) | Same soil after partial drying and re-wetting to field capacity |
|---|---|---|
| Coarse . . . | 6.8 | 8.5 |
| Medium. . . | 4.5 | 4.5 |
| Fine . . . . | 1.1 | 6.8 *) |

*) Fissures at the point of insertion of the electrode.

The data in Table IV show that the medium aggregated soil did not evince any change in oxygen diffusion while a very great increase of oxygen diffusion was noted in treatment *F* after drying and re-wetting while the electrode remained inserted. Some increase was also found with treatment *C*: this can tentatively be explained by better contact of soil with electrode, owing to a certain decrease in size of aggregates, with successive wettings. The data of Table IV confirm therefore the view expressed above, with regard to influence of fissures on aeration and root growth.

As cuttings produced more roots, and these elongated into the finely aggregated soil, the effect of fissures became of less consequence. Therefore at the second harvest date, although organic matter values of treatment *F* are somewhat higher than those of *M*, only an insignificant portion of the variance could be allotted to the comparison between *M* and *F*, while the difference *C* vs. *M* and *F* was significant at the 0.01 level.

A greater amount of root growth per cutting was therefore found in treatment *C* than in both *M* and *F*. While root initials have been found at an early date in treatment *C* as well as in other treatments, their subsequent elongation has been delayed in treatments *M* and *F* possibly by a low supply of oxygen [2]).

While it is evident that a fine textured soil is not an ideal rooting

medium, it should be pointed out that only a small percentage of the cuttings harvested on March 11th were found not rooted at all ($C$ : 8.5%; $M$ : 30%; $F$ : 13.5%). These figures compare well with results of a recent rooting experiment carried out with the same carnation variety [1]) in a sand-bed, in which percentages of non-rooted cuttings ranged, with the best hormonal treatments, between 8 and 25 per cent.

We may conclude that treatment $M$ seems to be definitely unsuitable in providing soil for a rooting bed; in treatment $F$ the fissures at the point of insertion of cuttings may partly counterbalance the low rate of oxygen diffusion found in this soil, but this does not seem to justify its use in a rooting bed. Soil of treatment $C$ can be used for rooting carnations if a light soil is not available. It should even have the advantage of a better water-holding capacity, as compared with a sandy medium.

## SUMMARY

Cuttings of a carnation variety of the Chabaud type were rooted in a fine textured soil which had been broken down to yield 3 different soil structures, $C$, $M$ and $F$ (coarse, medium-sized and fine aggregates).

Root initials were found in the basal callus of cuttings growing in all soil treatments already two weeks after planting.

Throughout the rooting process, the best results were obtained with coarse aggregated soil and the worst with the medium aggregated one. The fine aggregated soil showed intermediate results, probably due to fissures formed at the point of insertion of cuttings, which improved aeration.

The amount of roots at the end of the experiment was greatest with cuttings from the $C$ treatment, while those of $M$ and $F$ treatments did not differ significantly in this respect.

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# EXPLORATORY POT EXPERIMENTS ON SENSITIVENESS OF DIFFERENT CROPS TO SODIUM: C. FLAX

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## INTRODUCTION

Besides spinach [9]), oats [10]) and barley [34]), probably flax also has to be reckoned among the crops with a fair ability to take up sodium. Indeed various investigators agree that flax responds favourably to sodium in yield and quality (see under Discussion).

Here three pot experiments with flax (executed in 1943 and 1952) will be described. These were designed to investigate the sodium question further.

## EXPERIMENTAL SECTION

The lay out of the trials was exactly analogous to that described earlier for oats [10]), except for the dosage of nitrogen. The flax received 250 mg of nitrogen of which 100 mg was given at the beginning of the experiment and the remainder in two portions of 100 mg and 50 mg respectively as topdressing. Pots were set up in triplicate and 30 plants were left in each pot after thinning. The variety was "Concurrent".

A. *Flax in glass pots on mixtures of dusarit-quartz sand* (1943).

The plants with $Ca(NO_3)_2$ and 1% K-dusarit lagged behind in growth almost from the beginning (Plate I). They also were of a lighter colour and flowered later than the other plants. On the other hand plants treated with $Ca(NO_3)_2$ and 8% K-dusarit showed a more extensive withering of the leaves at the base of the stems than those of all other treatments. At the time of flowering, which

coincided with a period of cold and humid weather, the heads of the plants receiving $NaNO_3$, especially if receiving 8% K-dusarit also, began to flag and partly broke. They stiffened again when the weather turned more sunny, but never completely recovered.

In the final stage the group receiving $Ca(NO_3)_2$ and 1% K-dusarit possessed the worst straw, which was short and unhealthy in appearance, though uniform in stand (Plate II). The best impression was given by the plants with $Ca(NO_3)_2$ and 3% K-dusarit, which were well developed and uniform, whereas those with $Ca(NO_3)_2$ and 8% K-dusarit lagged behind. Those of the series with $NaNO_3$ were the best as regards development, but somewhat uneven in stand.

TABLE I

Average yields of flax on dusarit-sand (1943)

| Dressing | Straw in g air-dry matter per pot | Grain in g per pot | Grain in mg per fruitlet | Weight in mg air-dry matter per capsule | Number of fruitlets per pot |
|---|---|---|---|---|---|
| $NaNO_3$–1% K | 19.4 ± 1.51 | 1.0 | 13 | 15[5] | 83 |
| ,, 3% K | 19.6 ± 2.42 | 3.0 *) | ± 17 | 16 | 88 *) |
| ,, 8% K | 21.1 ± 2.64 | 1.5 *) | ± 12 | 15[5] | 53 *) |
| $Ca(NO_3)_2$–1% K | 12.3 ± 0.46 | 3.3[5] *) | ± 26 | 10 | 100 *) |
| ,, 3% K | 18.9 ± 0.23 | 5.0 | 34 | 11 | 148 |
| ,, 8% K | 16.9 ± 1.62 | 2.9 | 26 | 12 | 113 *) |

*) The weights of single pots vary considerably.

In this experiment sodium stimulated the vegetative development of flax, even at a high potassium level giving greater yields for the three K-levels by 58, 4 and 25% respectively. This effect was also evident from the weight of the capsules, which was much higher for the $NaNO_3$-plants. On the other hand, sodium in combination with an excess of potassium caused the heads to droop, a phenomenon which may be considered as a form of calcium deficiency. Millikan[17]) and Hewitt[6]) give as a symptom of calcium deficiency the wilting of the apex, a phenomenon which occurs especially on acid soils. In our experiment the drooping of the heads occurred particularly at a high potassium level, but the grain yield was depressed with all $NaNO_3$ treatments, suggesting that excessive sodium decreases the calcium content of the seeds. In the later experiment of 1952 special attention was paid to the dosage of sodium.

Plate I. Flax on dusarit, early stage

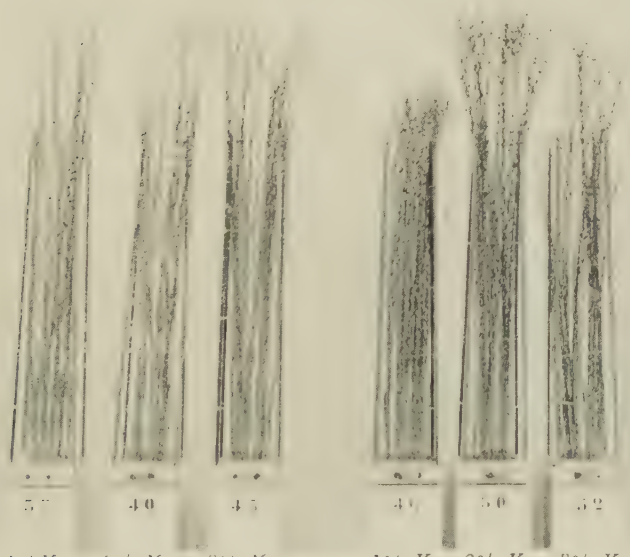


Plate II. Flax on dusarit, final stage

Plate III. Flax on humic sandy soil, final stage

B. *Flax in glass pots on humic sandy soil* (1943)

In this soil the young flax plants apparently had to cope with too ample nitrogen supply. Compared with series A the development of the plants was retarded and they had a darker green colour and were less erect. These characteristics remained even after the crop had overcome its initial depression. The stand was then excessively luxuriant so that in field conditions lodging would no doubt have occurred coupled with poor quality of the fibres. Flowering also occurred later than in series A and all heads drooped by their own weight and maturation was retarded. In the end however the plants cultivated on soil overcame their earlier defects and even exceeded in length the plants on dusarit. Series B was harvested two weeks later than series A.

Owing to their slow development very little difference could be observed between the different treatments. Initially potash dressing in combination with nitrate of lime gave a depression of the stand, but it improved with chilean nitrate of soda. In the final stage (see Plate III) the stand of the plants was generally very even. The plants with nitrate of lime were a little longer than those with chilean nitrate, but the latter yielded heavier straw.

TABLE II

Average yields of flax on humic sandy soil (1943)

| Dressing | Straw in g air dry matter per pot | Number of fruitlets per pot | Grain in g per pot | Grain in mg per fruitlet | Weight in mg air dry matter per capsule |
|---|---|---|---|---|---|
| Ch. N., no K | 24.8 ± 1.92 | 139 | 6.3 | 45 | 18 |
| ,, 300 mg KCl | 26.0 ± 0.36 | 157 | 7.1 | 46 | 18 |
| ,, 700 mg KCl | 26.1 ± 1.21 | 160 | 6.8 | 43 | 18 |
| N. of L., no K | 23.6[5] ± 0.66 | 203 | 8.0 | 39 | 13 |
| ,, 300 mg KCl | 24.5 ± 1.00 | 205 | 8.9 | 43 | 13 |
| ,, 700 mg KCl | 24.5 ± 0.31 | 208 | 9.4 | 45 | 13 |

The results show that a better vegetative development of flax (5-6½%) also occurred in soil by sodium fertilisation. This is very important since the soil itself already contained 200 me of exchangeable sodium per pot. Combining the results of the treatments with 300 and 700 mg KCl per pot the difference between the two N-fertilizers was 26.03—24.50 = 1.53 g with a mean error of 1.16. Between the treatments chilean nitrate with 300 mg KCl and

nitrate of lime with 700 mg KCl a significant difference was found. The weight of the capsules of plants grown in soil was also increased by dressing with sodium.

As in the case of the dusarit-series the grain yield of plants treated with $NaNO_3$ (chilean nitrate) was lower than those with $Ca(NO_3)_2$ (nitrate of lime), owing to a smaller number of matured fruitlets per pot although the amount of seed per fruitlet was rather higher for chilean nitrate.

The original intention to retten the material of the 1943 experiments (A and B) for quality determination could not be followed up as it got lost in 1944. No determinations of the strawlength could be made either.

C. *Flax in glass pots on mixtures of dusarit-quartz sand* (1952)

Pots with 2.4 kg quartz sand + 100 g dusarit; water supply at 60% of the waterholding capacity. Basic dressing: 540 mg $CaHPO_4.2aq.$, 15 mg $FeCl_3$, 40 mg $MnSO_4.4aq.$, 50 mg $CuSO_4.5aq.$, 5 mg borax and another 100 mg $FeCl_3$ after thinning. Sodium: levels of 0; 6; 12 and 18% Na-dusarit; all mixtures contained in addition 6% K-dusarit and 6% Mg-dusarit and were made up to 100% with Ca-dusarit. The pH of the mixtures was 6.2. Nitrogen: 250 mg N in the form of $NH_4NO_3$ as follows: 100 mg at the beginning of the experiment, 100 mg and 50 mg as first and second topdressing respectively. Pots in quintuplicate with 30 plants per pot (variety "Concurrent"), sown on the 10th of April.

After a smooth germination and initial development a depressive influence of the higher sodium levels became apparent after about a month. It was, however, temporary, as can be seen from the following measurements of development in length.

TABLE III

| Average length of flax plants in cm (1952) | | | | | |
|---|---|---|---|---|---|
| | May 14 | May 21 | June 4 | June 18 | July 3 |
| 1. 0% Na | 27 | 47 | 89.5 | 100 | 100 |
| 2. 6% Na | 28 | 46.5 | 88.5 | 100 | 100 |
| 3. 12% Na | 26 | 44.5 | 87.5 | 95 | 100 |
| 4. 18% Na | 24 | 40.3 | 79.5 | 86 | 100 |

As a result of this depression, the flowering stage, final development and maturation of the seeds were delayed in treatments 3 and 4. On the 7th of June the tops of these plants were drooping and wilting in a manner similar to that described under A. This

occurred during a period of very warm weather, after the early part of the summer had been cool and dry.

The plants recovered on increasing the water supply and thereafter new heads began to develop. The wilting of heads of flax also occurs in agricultural practice, especially after a dry period if the plants are already in the flowering stage. We are inclined also to ascribe the wilting of the apex in groupes 3 and 4 to physiological drought, caused by an excess of sodium. This assumption is supported by the evaporation figures for the total growing period, which for the treatments 1, 2, 3 and 4 amounted to 9.81; 8.88; 8.43 and 7.76 l per pot respectively. Apart from this influence on the water economy of the soil complex, excess of sodium is likely to provoke a condition of calcium deficiency in the plant.

TABLE IV

Average yields and quality of flax (Concurrent) on dusarit-quartz sand (1952)

| Treatment % Na | | Straw in g air-dry matter per pot | Ribbon in % | Ribbon in g | Percentage of waste | Usable part of ribbon in g | Usable part of ribbon in % of treatment 1 | Quality in florins | Total return in % of treatment 1 |
|---|---|---|---|---|---|---|---|---|---|
| 1. | 0 | 28.0 ± 2.05 | 18.0 | 5.04 | 6 | 4.74 | 100 | 1.87[5] | 100 |
| 2. | 6 | 29.8 ± 0.20 | 19.6 | 5.84 | 0.9 | 5.79 | *122* | 1.95 | *127* |
| 3. | 12 | 29.4 ± 0.83 | 19.1 | 5.61 | 0.9 | 5.56 | 117 | 1.97[5] | 123 |
| 4. | 18 | 28.6 ± 0.83 | 17.9 | 5.12 | 0.9 | 5.07 | 107 | 1.95 | 111[5] |

There were only slight insignificant differences in straw yields between the four treatments, but they showed a regular trend, suggesting that sodium stimulates the vegetative development of flax with a maximum effect at about 6% of sodium in the complex.

More important than this effect of sodium in increasing the yield is its effect on quality, which is based upon:

*a.* an increase of the percentage of ribbon (percentage of fibres),

*b.* a decrease of the percentage of waste (short fibres, which fall out on working),

*c.* a better market value.

On this basis treatment 2 (6% Na) yielded 22% more than treatment 1 (without sodium), which means an increase in price value of 27%. The increase in value was almost the same for treatment 3 but declined decidedly for treatment 4. From the point

of view of economic value the improvement of quality by sodium is very important.

For technical reasons, connected with the working of the straw, it was not possible to harvest the grain and fruitlets in this experiment.

## DISCUSSION

It is practical experience that the results of the cultivation of flax may be very precarious and that the nature, form and amount of fertilisation play an important part in determining success or failure. This is also confirmed by the results of various investigations described in literature.

Various German investigators have emphasized the importance of potassium for the formation and quality of the fibres (see compilation by Scheel [25]; also [16] [32])). It is said, however, that the chloride ion, which unlike the sulphate ion is easily absorbed by flax [22] [3]), exercises an adverse influence on the composition of the fibre so that better results are obtained with potassium sulphate than with muriate of potash [22] [3] [28] [27] [16]).

Contrary to the opinion of the German authors, other investigators find little or no influence of potassium on the development of the fibres and their yield [2] [11] [12] [18] [20]).

Three factors may be mainly held responsible for the apparent disagreement between the results of different experiments:

1. The effect of potassium will depend on the nitrogen and phosphate level, both that present in the soil and that applied in fertilisation. According to Milthorpe [18]) the influence of potassium on the fibre is only favourable when an ample P and N-supply is available.

2. With nitrogen fertilisation in ammoniacal form, flax makes heavier demands on the potassium supply than if fertilised with nitrate nitrogen [29]).

3. Experimental results are also influenced by the amount of sodium introduced with the K-dressings.

From older publications it appears that kainite was considered a good source of potassium for flax [7]). At the time little attention was paid to the sodium in this fertilizer and it was even suggested that chlorides might have a favourable effect on formation and

quality of the fibre [26] [7] [30]). In this connection the former use of common salt for flax was also used as evidence [30]). There is sufficient evidence now available that chlorides have a disturbing effect on the quality of the fibre, so that the favourable results obtained with kainite, are likely to be due to the sodium contained in it. A confirmation of this view-point can be found in a recent publication by Opitz *et al.* [22]). In pot trials with flax they compared kainite with other forms of potassium showing that high doses of kainite acted rather unfavourably, whereas slight doses of kainite gave an equally good or even better fibre than a large dose of potash in the form of sulphate.

Flax is known to have a fairly large capacity to absorb sodium [11] [2] [13]) and to be moderately tolerant of saline conditions [1] [4] [5]).

Bower and Pierre [2]), experimenting with different crops, concluded that flax and oats "respond but little to potash fertilization because the sodium which they absorb substitutes for potassium in the plant and thereby lowers the crop demand for potassium".

Relatively little influence of either potassium or sodium chloride on straw yield was found by Larson [8]) in four pot experiments on loamy soil (except in one of them).

Milthorpe [18]) in sand-water cultures found that "high sodium gave greater dry weights and higher fibre yields than did high potassium when combined with high levels of nitrogen and potassium".

Molchanov and Dmitrieva [19]) carried out sand-water cultures with flax to which varying amounts of KCl and NaCl were added. They arrived at a very positive conclusion regarding the importance of sodium for flax, namely that "sodium plays a role of its own in the metabolism of flax, independent of potassium and performing some functions which are not yet clear but which cannot be performed by potassium".

Maschhaupt [14]) in a field experiment showed that nitrate of soda had a better effect on flax than sulphate of ammonia or nitrate of lime, which he explained as due to the presence of sodium in the first mentioned fertilizer.

Melnikova [15]) also described the results of experiments on nitrogen fertilization of hemp and flax in which nitrate of soda was the best source of N.

In general, however, experiments on comparison of nitrate of soda with ammoniacal fertilizers give no clear information on the value of sodium because the question is involved with that of quick and slow acting nitrogen. Various investigators have expressed preference for ammoniacal fertilizers if applied early, while for topdressing nitrates are considered more favourably (a.o. [24]) and [25])).

It is very probable that differences in the effect of nitrate- and ammoniacal fertilizers are also connected with their physiological alkaline or acid nature, so that the reaction of the soil can play an important part in the final result. This point has probably been neglected in the assessment of many trials.

In experiments by Opitz and Egglhuber [23]) sodium chloride was added to all N-fertilizers, so that no reliable conclusions can be drawn.

From the available literature the conclusion may be drawn that sodium has a favourable influence on the development and quality of flax straw.

In our trials sodium stimulated the vegetative development of flax, almost independently of the supply of potassium. Apart from this a favourable effect of sodium was established on the percentage of fibre, the quality (length) of the fibres and on the price value of the final product. It would be valuable to continue this research by studying the variation in the anatomical structure of flax fibres under the influence of both potassium and sodium. Investigations of this kind have been made for flax, cereals and potatoes at different potassium levels (see discussion by Scheel [25])). The results of potassium fertilisation have been found to include an increase in the number of vascular bundles, a thickening of the mechanical elements, the development of cells of a more regular shape and a general improvement in anatomical construction.

In this connection the investigations of Verona and Treggi [33]) and Treggi [31]) on the influence of sodium on the anatomy of wheat and lupins are of interest. It appears that sodium has a clear influence on the histology of these plants and contributes to a better formation of the vascular tissues and the surrounding supporting tissues. On the basis of our findings similar anatomical investigations with flax would be well worthwhile.

In our experiments the effect of sodium on flax has proved to be unfavourable in one respect, namely in the yield of seed. The actual cause of this must be sought in the phenomenon of drooping heads, which can be ascribed to a deficiency of calcium, induced by an

excess of sodium (especially in combination with excess of potassium). With a more normal dose of sodium (sufficient for a good vegetative development), this phenomenon did not occur (see experiment C).

Larson[8]) in his experiments on loamy soil established a favourable effect of sodium chloride on grain yields in three out of four cases.

SUMMARY

In three pot experiments the effect of sodium on the development of flax and its fibre quality was investigated. Sodium, applied either in the nitrate form or as dusarit in an artificial soil complex, stimulated the vegetative development, even in the presence of an ample K-supply. It also had a favourable effect on the quality of the fibre, which was greatest when 6 percent of the exchangeable bases were in form of sodium but gradually decreased at higher percentages. Overdosage of sodium, especially in combination with high potassium, induced a condition of calcium deficiency as diagnosed by the drooping of the heads (wilting of the apex), and resulted in lower grain yields.

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# MOTTLING AND MAGNESIUM DEFICIENCY IN OATS AND THEIR DEPENDENCE ON VARIOUS FACTORS

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## INTRODUCTION

In 1913 Elema found a soil defect, hitherto unknown in the Netherlands, on various reclaimed moorlands in the province of Drenthe, which was described by Hudig and Meyer [9]) under the name "Hooghalen disease" after the locality where it was first discovered. Owing to its frequent occurrence on the Dutch sandy and sand-peat soils this defect is now well known. Characteristic of the "Hooghalen disease" in cereals is the "curdling" of the chlorophyll, giving the leaves a mottled ("tigered") appearance. As the disease progresses, the amount of chlorophyll decreases and the plant becomes yellow-coloured; the chlorophyll seems to be restricted to small spots on a yellow background. At worst the plants attain a uniform dull and pale colour and show a considerable retardation in development. Young plants keep their normal stature with erect and apparently firm leaves. In light cases the symptoms are often of a temporary nature but serious outbreaks cause considerable losses of crop.

The real cause of the disease was not discussed by Hudig and Meyer. They found only that its occurrence was associated with a high acidity of the soil and therefore recommended an alkaline dressing as a remedy. It was in fact proved that the disease could often be prevented or cured by applying lime or Chilean nitrate (nitrate of soda), so that it became designated by some as "acid disease". Later investigations by Jessen [12]), Gehring *et al.* [6]) showed that a high acidity does not necessarily cause the mottled

colouring. The typical chlorotic symptoms did not appear after applications with salts of magnesium, but heavy dressings of magnesium without increasing the pH did not always appear to be sufficient for an optimum development of the crop, as was also demonstrated by Van Itallie[10]). Conversely, according to the experiments of Van Itallie[11]), attempts to restore the normal colour of the leaves by only increasing the pH were practically always unsuccessful.

Smit and Mulder[17]) showed that the symptoms of magnesium deficiency in water culture are in all respects identical with those of the "Hooghalen disease" on acid soil. By applying sufficient magnesium even the worst symptoms could be cured. In some cases on acid soils, however, although the symptoms had disappeared, the plants continued to grow poorly. Thus it would seem more accurate to designate the mottling and the more serious symptoms as "magnesium deficiency" instead of "Hooghalen disease"; the term "acid disease" is quite incorrect, as will be shown later.

The favourable effect of liming on the colour of the leaves is attributed by most investigators to an improvement in the magnesium supply. The investigators, however, do not agree as to the essential nature of this effect. According to Gehring[6]), Schmitt[14]) and Michael[13]) it is due to a mobilization of the magnesium which has been fixed by absorption in the acid soils. According to van Itallie[11]) the activity of the plant with regard to its uptake of magnesium is increased. Smit and Mulder[17]) consider mobilization to be of little significance and largely attribute the improved uptake of magnesium to a better root development after liming. In addition a combination of soil chemical and physiological influences is suggested as a possibility by Michael[13]). Van Itallie[10]) thinks, that apart from the Mg-content, the base surplus in the plant which is controlled by the acidity of the soil, may be of importance.

The favourable effect of liming could no doubt be partly ascribed to the magnesium, which is a constituent of practically all lime fertilizers. Small quantities of magnesium may be of great significance because of its considerable activity.

Besides the Mg-content and the pH of the soil, other factors have been found to influence the outbreak of the disease. Gehring[6]) pointed out the importance of the form and quantity of K-fertilizers and the form of N-fertilizers. Monovalent cations hamper the Mg-

uptake, nitrogen in the form of nitrate promotes the Mg-uptake and enhances the cation-anion ratio in the plant (van Itallie[11]). Castenmiller[1]) showed by statistical treatment that in interpreting the MgO-content of the soil, the humus content should be taken into account.

Although magnesium has received attention for nearly 25 years, investigators have only rarely mentioned any limiting values for the magnesia content of the soil. The difficulty in determining to a high degree such criteria is of course associated with the method of soil analysis which aims at determining small quantities which should be related to the quantity available to the plant; the high activity of magnesium necessitates an accurate method of determination. Strong solvents, such as 20% HCl proved to be unsatisfactory. Truninger[18]) and Hasler[7]) extracted with 10% HCl and no longer observed magnesium deficiency symptoms at contents above 0.1–0.3% and 0.3–0.6% MgO, respectively. These criteria, however, are of quite a different order from the limiting value of 60 ppm, determined in 0.1 *N* HCl, as mentioned by de Vries[19]). Using microbiological methods (*Aspergillus*), several investigators found the limiting value to be 150 ppm *).

More specific values were given by Castenmiller[1]). Using 0.5 *N* acetic acid as solvent he obtained limiting values which were higher in proportion as the humus content of the soil increased; for arable land on sandy soil with 5% humus he gives a limiting value of 30 ppm, in the case of 10% humus, 50 ppm. The limiting values may vary according to the kind of crop.

So far it has not been possible to obtain a quantitative relation between limiting value and pH (or K-supply). However, some results of trials on experimental plots described by Castenmiller[1]) and Sluijsmans[15]) suggested that the limiting value would be almost independent of the pH.

The investigations of Smit and Mulder and others have shown that the mottling in oats is caused by Mg-deficiency. It has been our aim to investigate the influence of various factors associated with mottling. Although previous investigators have provided im-

*) Shortly before receiving the proof of this paper we found more limiting values (50–120 ppm, determined in 0.025 *N* $CaCl_2$) mentioned by Schachtschabel (Schachtschabel, P., Das pflanzenverfügbare Magnesium des Bodens und seine Bestimmung. Z. Pflanzenernähr. Düng. u. Bodenk. **67**, 1 (1954)).

portant indications in a qualitative respect, the description of the quantitative significance of the factors has been insufficient.

More knowledge is needed concerning evaluation of the MgO-content of the soil and its interchange with other soil chemical factors in relation to the supply of crops.

An investigation into the significance of pH in this connection is necessary in view of the contradictory results obtained by previous investigators some of whom actually did find an influence of pH (Van Itallie[10] [11]; Smit and Mulder[17]), whereas others could not decide upon its influence with any degree of certainty (Castenmiller[1]; Sluijsmans[15]).

In the literature on the subject frequent reference is made to the K-supply but for practical purposes it is necessary to know the extent of its influence in terms of separate figures for the K-dressing and the K-content of the soil.

The influence of the humus content found by Castenmiller[1] must, wherever possible, be tested within a clearly defined soil unit, since his conclusions were based on investigations of soils with varying properties.

## METHOD OF CROP ASSESSMENT

Agricultural practice has shown that slight mottling in cereals does not affect the yield. This is corroborated by accurate observations on experimental fields. The symptoms of disease have proved to be a better guide than the yields. This experience has, in studying the Mg-supply of cereals, led us to focus our attention on mottling as a starting point. It goes without saying that our method of procedure demanded accurate observation.

A graphical or mathematical presentation of the observed phenomena required a practicable method of evaluating the various degrees of mottling. Sluijsmans[16] and his assistant Boskma suggested for this purpose a scale from 1 to 10. The figures correspond with the appearance of the plant according to the following table:

10 = no mottling, plant quite sound
9 = plant very faintly mottled
8 = plant faintly mottled throughout; mottling especially on leaf edges
7 = plant clearly mottled, but general appearance still green
6 = plant strikingly mottled; connected dark spots on lighter background; plant yellowish green

5 = plant considerably mottled; chlorophyll spots, largely detached, on yellow background; plant greenish yellow
4 = chlorophyll in great number of spots on yellow background; plant yellow
3 = plant clearly yellow with occasional distinct green chlorophyll spots
2 = plant strikingly yellow; little chlorophyll left
1 = plant completely yellow; no chlorophyll visible.

Experience has taught us that the employment of this scale results in satisfactory agreement between various valuers in judging the "syndrome" of one particular plant. In judging a crop in the field the important thing is to represent the diverse syndromes occurring on the plot as one average figure. This procedure naturally entails some variance between the figures of various valuers. The error in the evaluation of the mottling figures amounts to approximately 0.3 units (estimated area 48 sq. metres).

The relation between syndrome and yield will not be discussed in the present article, but it may be worth mentioning that according to observations on some trial fields under oats in 1953 a limit for decrease in yield was found, which corresponded to a syndrome of 7 to 7.5, *i.e. a syndrome with a figure higher than* 7.5 *was not associated with a lower yield.*

Anticipating the results, it may be worth noting in this connection that a visual assessment in studying the Mg-supply of cereals is of great importance. In several of the charts in this article responses can, to a large extent, be seen within the mottling range 7 to 10. These would not have been found if attention had been paid only to the yields.

## SOURCES OF DATA

The data are derived from 39 simple manurial experimental fields (crop: oats *var.* Marne), laid out in the "Gelderse Vallei" in 1953 under an extensive fertility research scheme in this area, which is characterized by "cover sands" and is situated in the centre of the Netherlands in the provinces of Gelderland and Utrecht.

The object of these field trials (treatment and non-treatment) was to check manurial effects. Each experimental field consisted of 6 subplots each of 48 sq. metres, arranged for K, P, PK (twice), PMg and PKMg. The additions per hectare in the form of various compounds were: 80 kg $P_2O_5$ as double superphosphate, 120 kg $K_2O$

as potassium salt (muriate of potash) 60%, 40 kg MgO as magnesium sulphate ($MgSO_4.H_2O$) and 50 kg N as nitro-chalk. These were applied at the time of sowing the oats. In this way the effect of the various fertilizers could be related to the contents of the corresponding elements in the soil (as determined chemically).

Prior to the experiment a soil sample was taken from each experimental field. The pH, humus content, content of exchangeable magnesium and K-number were determined.

The pH was determined in 1 *N* KCl. The organic matter content was calculated from the loss on ignition.

For the determination of exchangeable magnesium the soil was extracted with 0.5 *N* NaCl; the MgO-content was determined colorimetrically.

The K-number was flame-photometrically determined in a 0.1 *N* HCl extract (1 unit = 0.09 g $K_2O$ per 1000 g humus).

On the 11th and 12th of May 1953, the degrees of mottling were evaluated *) according to the above scale; the height of the crop varied from 10–30 cm.

About the 20th of May leaf samples were taken from the subplots and the total-N and MgO-content was determined.

The data obtained enable the influence of a magnesium fertilizer (at 40 kg MgO ha) on the appearance of mottling to be investigated. At the same time the relation between mottling and various soil factors can be studied **).

## STATISTICAL TREATMENT

In the introduction various factors which may influence mottling were discussed. In this series of field trials there was an appreciable variation in MgO-content, K-number, humus content and pH. Not only the influence of the Mg- and K-fertilizers on mottling can be studied therefore, but also the influence of these soil factors. The difficulties in computation are largely due to the fact that the experiments were made under natural conditions. Since many of the soil factors are interrelated it is often difficult to determine which particular factor is responsible for a given response. In drawing

*) The observations were made by K. Boskma, J. Bouwkamp and C. Sluijsmans.

**) A table with the compiled data is obtainable on request at the Agricultural Experiment Station and Institute for Soil Research T.N.O., Groningen, the Netherlands.

conclusions therefore great attention must be paid to eliminating any errors arising from these interrelationships.

We have confined ourselves to investigating the factors mentioned above. We shall try to give an answer to the question as to *what* factors can be shown to influence mottling. At the same time the investigation can be regarded as an attempt to find *the best way* of describing the influence of these factors.

The difficulty in a complete graphical method for analysing the observations (Ferrari [4]) is the comparatively small amount of data available and the great number of possible factors. For this reason we have employed a numeric graphical method described by Ezekiel [2]). This method involves a multiple regression calculation so as to eliminate the influence of the interrelationships. Afterwards a graphical technique provides a better approach to the study of the factors involved.

We assume that mottling $y$ is determined by a number of factors $x_1, x_2 \ldots x_n$; a sub-plot $k$ with certain values for these factors is associated with a mottling value $y^k$. The expectation value of mottling $E(y)$ is a function of the growth factors, *i.e.*

$$E(y) = f(x_1, x_2, \ldots x_n).$$

The object of this investigation is to obtain this function from the available data.

Our initial hypothesis is that this relationship is represented by the formula:

$$y = f_1(x_1) + f_2(x_2) + \ldots f_n(x_n) + c.$$

The terms $f_1(x_1)$, $f_2(x_2)$, *etc.* indicate that a (regular) change in $x_1$, $x_2$, *etc.* is associated with a (regular) change in $y$. This change may be curvilinear or rectilinear.

In contrast to the complete graphical analysis (Ferrari [4]) we assume the absence of *interactions*.

The processes are as follows. We begin by assuming that the terms $f_1(x_1)$, $f_2(x_2)$, *etc.* represent rectilinear changes. By means of the usual methods *) we compute the multiple regression equation:

$$y = b_{1.234}\, x_1 + b_{2.134}\, x_2 + b_{3.124}\, x_3 + b_{4.123}\, x_4 + c$$

the parameters $b$ and $c$ being the regression coefficients and the constant,

*) The required normal equation can be volved in various ways; we employed the Doolitle method (Ezekiel [2])).

respectively. *E.g.* in a particular case (PK-plots) the equation turned out to be:

$$y = 0.00466x_1 - 0.1348x_2 + 0.0070x_3 + 1.6305x_4 - 0.69$$

$x_1$, $x_2$, $x_3$ and $x_4$ representing the MgO-content, the humus content, the potassium content and the pH(KCl) of the soil, respectively. It should be noted that the regression coefficients are partial coefficients, *i.e.* they indicate the influence of a particular factor when all other (also correlated) factors are held constant.

Subsequently we compute from this regression equation the 39 estimates of $y$ by substituting in each case the corresponding values for $x_1$, $x_2$, $x_3$ and $x_4$. Each estimate $y'$ is then subtracted from the value $y$ that has actually been found; these differences $z'$ (residual values or deviations) for a number of the PK-plots have been given in Table I.

TABLE I

Mottling values $y'$ calculated from regression equation and the residuals (deviations) $z'$ (for PK-plots)

| Experimental field | $y$ | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $y'$ | $z'$ |
|---|---|---|---|---|---|---|---|
| 1 | 7.25 | 25 | 6.2 | 25 | 4.75 | 7.55 | —0.30 |
| 2 | 10.00 | 30 | 2.7 | 31 | 4.95 | 8.64 | 1.36 |
| 3 | 10.00 | 84 | 7.7 | 22 | 4.60 | 9.84 | 0.16 |
| 4 | 5.00 | 23 | 10.2 | 8 | 3.85 | 5.34 | —0,34 |
| 5 | 5.25 | 15 | 6.3 | 13 | 3.90 | 5.61 | —0.36 |
| . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . |

The values of $z'$ represent that part of the deviation in the mottling values which has not been covered by the linear regression equation. The accuracy of the estimate $y'$ is given by $\sqrt{\Sigma(z')^2/(n-m)}$ in which $n$ denotes the number of data and $m$ the number of degrees of freedom. Accuracy may possibly be increased by a further, but graphical, process. This graphical analysis is made as follows. Suppose that pH ($= x_4$) has the greatest influence. The mean values of $x_1$, $x_2$ and $x_3$ are now substituted in the regression equation, giving the equation

$$y = 1.6305x_4 + 0.27.$$

This equation, presented graphically in Figure 1, shows the relation between $x_4$ and $y$ ($y$ estimated from $x_4$) in the case of mean values for the other factors. Then for each case the residual values $z'$ are added in the graph; along the abcissa the corresponding $x_4$ value is measured off and along the ordinate the corresponding $z'$ value is measured off, the regression line serving as zero basis. The result for plot 2 is indicated in Figure 1 by a circlet, *etc.* The spread of the points about the line has been reduced because the influences of $x_1$, $x_2$ and $x_3$ (provisionally assumed to be rectilinear) have

been eliminated. Figure 1 now offers the possibility of a better approach to the equation $y = f_4(x_4)$.

To this end we draw a freehand curve, passing as well as possible through the swarm of points; this fitting takes place in a direction parallel to the $y$-axis. The easiest way to do this is to determine the mean (indicated by x) of a limited number of groups of points; then through the mean points a smooth curve is drawn. The result, $y = f'_4(x_4)$ is shown in Figure 1.

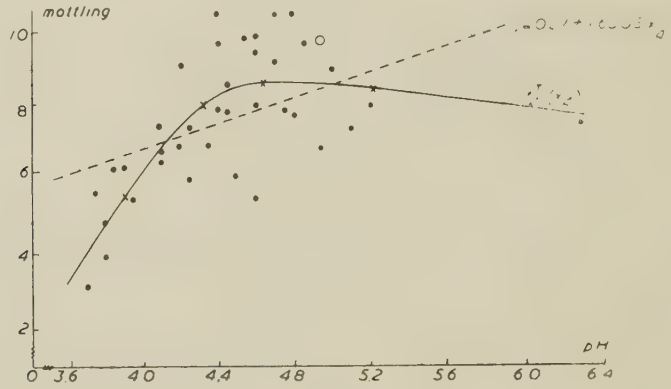


Fig. 1. The assumed rectilinear influence of pH on the degree of mottling and the first graphical approximation.

The equations $y = f'_1(x_1)$, $y = f'_2(x_2)$ and $y = f'_3(x_3)$ can be determined in the same way by means of the equations $y = 0.0466x_1 + 6.14$, $y = -0.1348x_2 + 8.28$ and $y = 0{,}0070x_3 + 7.48$. The corresponding curves cannot be given through lack of space.

Ultimately we obtain four curves which provide a better estimate of the influences of the various factors on mottling than the supposed linear influences. The influence of each factor is determined after eliminating the supposed rectilinear influences of the other factors. It is to be expected that elimination by means of the curves obtained last will result in a better estimate of these influences.

The subsequent procedure is as follows: a new valuation $y''$ of $y$ is obtained by means of the equation

$$y'' = f'_1(x_1) + f'_2(x_2) + f'_3(x_3) + f'_4(x_4) + c';$$

$y''$ indicates that it is a second estimate of $y$. The constant $c'$, which differs from the constant $c$ in the linear regression equation, is computed according to the formula:

$$c' = y - \frac{\Sigma\,[f'_1(x_1) + f'_2(x_2) + f'_3(x_3) + (f'_4(x_4)]}{n};$$

the summation is made for the 39 sets of values. The values for $f'_1(x_1)$, $f'_2(x_2)$, *etc.* are obtained by substituting the values of $y$ obtained from the

appropriate curve for the field trial, *e.g.* in the case of $x_4 = 4.75$ this is 8.50, in the case of $x_4 = 4.95$ this is 8.45, *etc.* The result has been partly shown in Table II. By means of the regression equation found the second estimate $y''$ of $y$ and the residuals $z'' = y - y''$ can then be computed.

TABLE II

Computation of the second estimate $y''$ of $y$ and the residuals (deviations) $z''$ (for PK plots)

| Experimental field | $f'_4(x_4)$ | $f'_1(x_1)$ | $f'_2(x_2)$ | $f'_3(x_3)$ | $\Sigma f'$ | $c'$ | $y''$ | $x''$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 8.50 | 7.35 | 7.40 | 7.65 | 30.90 | — 22.67 | 8.23 | —0.98 |
| 2 | 8.45 | 7.70 | 7.90 | 7.70 | 31.75 | | 9.08 | 0.92 |
| 3 | 8.45 | 10.60 | 7.20 | 7.60 | 33.85 | | 11.18 | —1.18 |
| 4 | 5.15 | 7.10 | 6.90 | 7.50 | 26.65 | | 3.98 | 1.02 |
| 5 | 5.50 | 5.75 | 7.40 | 7.55 | 26.10 | | 3.53 | 1.72 |
| . | . | . | . | . | . | | . | . |
| . | . | . | . | . | . | | . | . |
| . | . | . | . | . | . | | . | . |

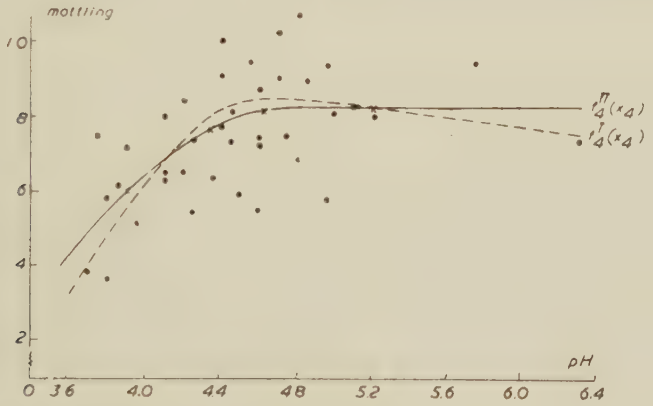


Fig. 2. The influence of pH on the degree of mottling; first and second graphical approximations.

In Figure 2 we have started from the function $y = f'_4(x_4)$. The unexplained residual values $z''$ are again added in this graph, the curve serving as zero basis. We now ascertain the possibility of obtaining a new curve from the swarm of points. A smooth curve is now drawn as well as possible through the swarm of points; fitting is again made easiest by determining the means for a number of groups. The curve $y = f''_4(x_4)$ given in Figure 2 is now provisionally assumed to be the best estimate of the function $y = f_4(x_4)$.

The same process is applied to the other factors, so as to obtain provisionally best estimates for the functions $y = f_1(x_1)$, $y = f_2(x_2)$ and $y = f_3(x_3)$.

It is usual to apply further approximating processes in this way; definite

estimates are generally obtained after 3 or more repetitions. Smaller values for the standard deviations of $z$ indicate that the last result can, to some extent, be regarded as a better estimate of the "true" influence. Further repetitions can be considered unnecessary when the standard deviation of $z$ no longer shows a decrease.

The curves ultimately found can be represented in various ways. $Y$ may be expressed in terms of absolute values; another possibility, however, is to do this only for the most important factor, the influence of the other factors being represented as deviations. Only the first method is used in this publication.

This briefly described statistical method has the advantage of providing a quick way for describing a limited number of data; the disturbance introduced by correlations between the independent factors is eliminated as much as possible.

The method has, however, certain disadvantages. In the first place no interactions are indicated and in our particular problem this proved to be important. A purely additive conception about the influence of MgO-content and pH does not lead to entirely correct results. One result may be that after correction in the several repetative stages, mottling figures over 10 are obtained. This will be referred to later.

A second disadvantage is that the curves obtained relate to mean values of $y$, corresponding to the other factors. Consequently, in the case of a sufficient magnesium supply, expressed by the asymptotic part of the curve, this part remains below 10. A vertical upward shift from the curve, parallel to the $y$-axis is sometimes permissible. This shift is only possible if its validity is evident from other investigations.

A method of indicating the statistical reliability of the results was described by Ferrari [3) 4)]. Reference was then made to the possibility of making a final attempt to improve upon the function found graphically. This can be done be choosing from all possible equations of the form

$$y = a_1 . f_1(x_1) + a_2 . f_2(x_2) + a_3 . f_3(x_3) + a_4 . f_4(x_4),$$

in which $a_1$, $a_2$ *etc.* represent coefficients to be determined, the one which gives the best agreement with the actual experimental results. In this particular case there are in each case 39 possible equations,

$$y^k = a_1 . f_1(x_1^k) + a_2 . f_2(x_2^k) + a_3 . f_3(x_3^k) + a_4 . f_4(x_4^k) \quad (k = 1, 2, 3, \ldots 39).$$

The normal equations which can now be formed enable the best estimates for $a_1$, $a_2$, $a_3$ and $a_4$ to be made. We expect that the best estimate, $\bar{a}_i$ ($i = 1, 2, 3, 4$) will be in the vicinity of unity and the deviation of $\bar{a}_i$ from zero (0-hypothesis) can be tested by means of their standard errors.

For a given level of probability $p$, those functions in which $\bar{a}_i$ lies between the two limits $a_i''$ and $a_i'$ (where $a_i' < a_i''$) are acceptable. If 0 occurs within these limits then $f_i(x_i) = 0$ is also an acceptable estimate and the experimental data can be described, omitting the particular factor concerned.

It may also be asked to what extent $a_i' = 0$ and $a_i'' = \infty$ are probable. This entails the calculation of the one tailed of a confidence interval for $a_i$ of 0 to $\infty$. If the probability is high (*e.g.* 0.05) then $f_i(x_i) = 0$ is an acceptable estimate.

It is clear that in determining the probability $p$, allowance should be made for the number of degrees of freedom. For the computation of $p$ the graph in E z e k i e l 's book was used [2]).

## MOTTLING AND ITS DEPENDENCE ON VARIOUS FACTORS *)

We have tried to describe the extent of mottling in each trial plot in terms of four soil factors: magnesia content, pH (KCl), K-number and humus content. Plots PK (twice) and K have been represented together, because an effect of the phosphate fertilizer could not be demonstrated. By graphical analysis we find the effect of these soil factors on the degree of mottling in oats, with or without a potassium fertilizer, combined or not combined with a magnesium fertilizer. The influence of the fertilizers can be determined by comparing the effect of various additions.

It has already been said the level of the curves obtained is somewhat misleading. The explanation is that the level is closely connected with the mean mottling figure to which the correction is applied. In studying the results therefore, it will be advisable to pay more attention to the form of the curves and to differences in slope between the curves (interaction) than to the level. With this method of statistical analysis it is impossible to determine interactions directly. On the other hand the presence of interactions between dressing and soil factors may appear from a comparison

*) The computations have been made under the direction of P. H o l s t e i n.

between the curves. Its reliability can be computed when those factors are investigated, which determine the extent of the differences between treatment and non-treatment. Some idea of the interactions between the soil factors is obtained by dividing the data into groups *e.g.* a low and a high pH. The two groups are then analysed separately.

For the sake of completeness it may be mentioned that the mean magnesia content, the K-number, the pH and the humus content of these 39 trial fields are 31.8, 20.1, 4.51 and 4.9, respectively. These should be taken into account in considering the results.

Let us begin with the results for the P-plots. The 4 soil factors mentioned earlier are included in the investigation. The results are shown in Figures 3, 4, 5 and 6.

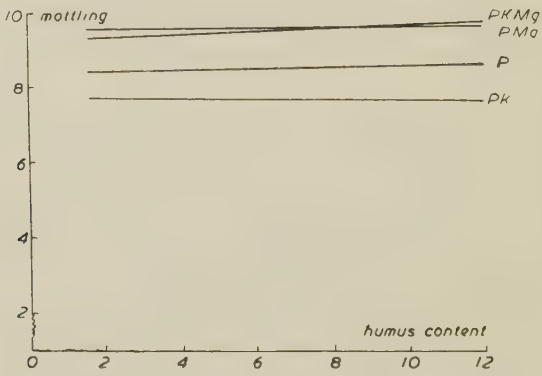


Fig. 3. The relation between humus content of the soil and the degree of mottling for different treatments. For the meaning of the difference in curve level in this and following charts, see text.

What is most striking is the absence of any effect of the humus content of the soil. In the Netherlands consideration is given to the humus content when advice is given to farmers concerning magnesium applications (C a s t e n m i l l e r [1])). The new results imply that the humus content does not play an essential role in the appearance of mottling. The humus content is probably an indication of certain (unknown) soil conditions that influence the magnesium supply. On all trial plots this effect was found to be absent (Figure 3). According to this investigation therefore, it would seem that no allowance need

be made for the humus content in practical advisory work in a more or less uniform area.

The considerable influences of the magnesia content and the pH of the soil are also of striking interest (Fig. 4 and 5). The form of the

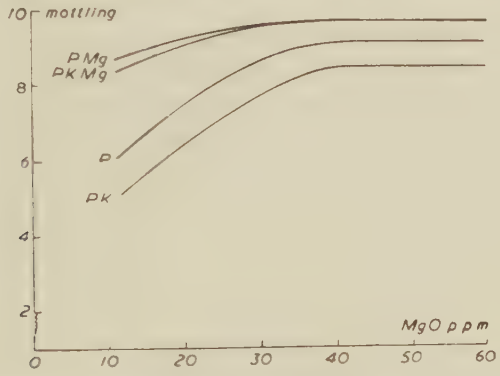


Fig. 4. The relation between MgO-content of the soil and the degree of mottling for different treatments.

curves for magnesia content and for pH is approximately the same. Despite the differences in scale, the impression is that the influence of the pH is greater in the variation occurring in this area. The

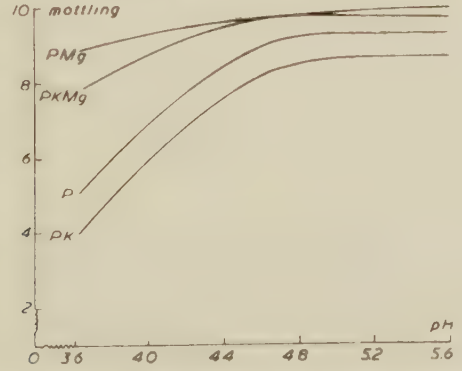


Fig. 5. The relation between pH of the soil and the degree of mottling for different treatments.

limiting value for the magnesia content is about 35–40 units; the limiting value for pH is about 4.80.

The antagonistic action of potassium is evident from Figure 6;

the higher the potassium number of the soil, the higher appears to be the degree of mottling. A rise of the potassium number of 20 units increases the degree of mottling by 1.5 points.

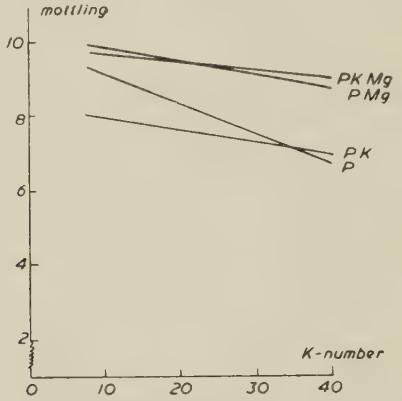


Fig. 6. The relation between K-number and the degree of mottling.

The result of the investigation into statistical reliability is shown in Table III.

TABLE III

| The coefficients $\bar{a}_i$ and the probabilities $p_i$ for P-plots | | | |
|---|---|---|---|
| Factor | $\bar{a}_i$ | $s_{\bar{a}_i}$ | $p(a'_i = 0)$ |
| magnesia content . . . . . | 0.77 | 0.29 | 0.008 |
| pH. . . . . | 1.03 | 0.21 | 0.000 |
| K-number . . . . . | 1.07 | 0.33 | 0.003 |

From this it appears that the effect of magnesia content has been somewhat overestimated, because $\bar{a}_i$ ought to be 1. The ultimately best estimate is therefore obtained by multiplying the scale of the mottling axis by $1/\bar{a}_i$. The influence of the other factors has been estimated correctly. We have set the level of significance at 0.05. The last column of Table III indicates that the statistical reliability is very high in all cases.

Proceeding to the discussion of the results obtained for the PK-trial plots, it will be seen that similar results were obtained (Figures 3, 4, 5 and 6). There is no influence of humus, the effect of the mag-

nesia content and the pH are considerable, and there is less influence of the K-number.

It appears to us that the curves for the PK-plots are in all cases lower than the corresponding curves for the P-plots. An explanation for this has been given previously.

The only difference between the two plots is the amount of potassium applied. We know that the action of potassium is antagonistic; in consequence the average degree of mottling on the PK-plots is greater. Corrections applied to the mean mottling figure therefore lower the whole PK-curve. It may be possible therefore to nullify an injurious antagonistic action of potassium by adding an adequate amount of magnesium.

The statistical reliability of the results is indicated in Table IV.

TABLE IV

| Coefficients $\bar{a}_i$ and the probabilities $p_i$ for PK-plots | | | |
|---|---|---|---|
| Factor | $\bar{a}_i$ | $s\bar{a}_i$ | $p(a'_i = 0)$ |
| magnesia content | 1.00 | 0.18 | 0.000 |
| pH | 0.97 | 0.14 | 0.000 |
| K-number | 0.84 | 0.55 | 0.065 |

The statistical reliability of the factors, magnesia content and pH, is very high. The probability $p$ for the effect of the potassium number is slightly too low; under the circumstances therefore, we can only conclude that there is an indication of some influence of the potassium number. Indeed, other trial plots also showed evidence that the influence of the K-number decreases when potassium has been applied.

The effect of the various soil factors has decreased considerably following an addition of 40 kg MgO. A magnesia treatment to this extent not only largely succeeds in obviating the injurious effect of too low a MgO-content of the soil, but also too low a pH. As already stated, this was known previously. It will be appreciated that from the beginning the appearance of mottling has been associated with a poor magnesium supply. The question is whether the defect can be entirely prevented by larger additions of magnesium. Other investigations have demonstrated that complete prevention is indeed possible in this way.

A shift in level is again apparent, now in an upward direction.

The explanation is, of course, that due to the magnesium treatment there is a lower average incidence of mottling.

The same is true for the plots treated with both magnesium and potassium. The antagonistic action of the potassium is now, however, less apparent.

It is clear that these more or less considerable influences with a similar number of data are statistically less reliable. This is shown in Table V.

TABLE V

The coefficients $\bar{a}_i$ and the probabilities $p_i$ for the PMg- and PMgK-plots

| Factor | PMg | | | PMgK | | |
|---|---|---|---|---|---|---|
| | $\bar{a}_i$ | $s\bar{a}_i$ | $p(a'_i = 0)$ | $\bar{a}_i$ | $s\bar{a}_i$ | $p(a'_i = 0)$ |
| MgO-content . | 0.74 | 0.55 | 0.088 | 0.42 | 0.48 | 0.20 *) |
| pH . . . . . | 0.78 | 0.46 | 0.050 | 1.10 | 0.35 | 0.005 |
| K-number . . | 1.29 | 0.77 | 0.053 | 0.86 | 0.88 | 0.160 |

*) Extrapolated from the graph

The supposition that there is no influence of various soil factors is in most cases not contradicted by the data and the hypothesis based on a curve may therefore be rejected. In some instances, however, there is a more or a less strong indication of an influence. Only in the case of pH the zero hypothesis must be rejected for both plots. This shows that a magnesium treatment can more or less completely counteract a low MgO-content (in fact, the effect of the magnesia content has in one case been considerably overestimated); this is not (yet) the case for the pH with a treatment of 40 kg MgO.

A consideration of each figure individually will provide a clear survey of the influences of the various treatment on the effects of the soil factors.

Figure 4 shows the influence of a potassium or magnesium dressing singly or combined, on the appearance of mottling with various magnesia contents of the soil. If the slope and the form of the curves are compared, the influence of a magnesium treatment proves to be considerable. The difference in level is, as already shown, misleading. From investigations by S l u ij s m a n s we know that no mottling appears on a soil containing sufficient magnesium, but that improving the pH only is not effective enough (Figure 7). This information enabled us to construct Figure 8, in which the difference in

level has been eliminated by vertical displacement. The shift to the left of the limiting value when a magnesium treatment is given or a potassium treatment is omitted, is demonstrated. An addition of 40 kg

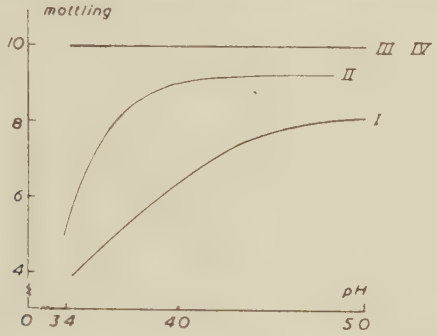


Fig. 7. The influence of the pH on the degree of mottling in oats on reclaimed peat soil; I at low MgO-content, IV at high MgO-content of the soil.

MgO brings about a decrease in mottling, which at the most is equal to a rise in the magnesia content of the soil by 12 to 13 units. The effect of a fresh treatment is therefore smaller than the corresponding amount of magnesia in the soil, as extracted with NaCl.

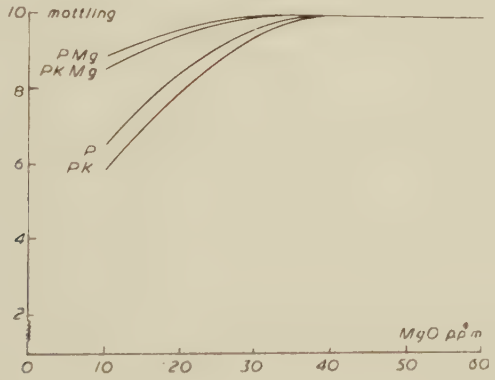


Fig. 8. The relation between MgO-content of the soil and the degree of mottling, after correction for the difference in level.

It may be asked whether the differences between the subplots are real, *i.e.* whether the interactions between the magnesia content and the various treatments are statistically reliable. An answer to this has been found by resorting to the following device. The differ-

ences in mottling due to the fertilizers have been related to the various soil factors. If the P-plot shows mottling 9 and the PK-plot 7, the difference 2 is then used as the dependent factor. The result of this analysis therefore shows by *what* factors this difference is determined and *in what way* this difference, between *e.g.* the P-plot and the PK-plot, is influenced by the factors found. After this the statistical reliability of the results can be tested.

As expected the results of this method of presentation confirm the conclusions that could be drawn from the Figures 3, 4, 5 and 6. The magnesium and the potassium status of the soil influence the response to the potassium treatment. In fact, there proved to be no influence of the pH; in Figure 5 the pH curves may coincide completely by vertical displacement. The statistical reliability is shown in Table VI.

TABLE VI

| The coefficients $\bar{a}_i$, and the probabilities $p_i$ for the differences between P- and PK-plots | | | |
|---|---|---|---|
| Interaction between potassium treatment and: | $\bar{a}_i$ | $s\bar{a}_i$ | $p(a'_i = 0)$ |
| magnesia content . . . . . | 1.10 | 0.44 | 0.010 |
| potassium number . . . . . | 0.78 | 0.35 | 0.018 |

The interactions between potassium treatment on the one hand, magnesia content and potassium number on the other, are statistically reliable so that an assumption of the existence of these interactions is justified.

Sluijsmans found that on an experimental area on a reclaimed moor soil (sand-peat) it was impossible to compensate too low a magnesium status by increasing the pH; this is shown in Figure 7. A vertical shift, apparent for the effect of the magnesia content in Figure 8, is therefore presumably not permissible for the pH.

The interactions between the treatments and the soil factors have also been studied for the PMg- and P-plots. The result is a different representation of the differences between the PMg- and P-curves in Figures 3, 4, 5 and 6. We can again demonstrate an effect of the magnesia content, the pH and the K-number on magnesium treatment effect. The statistical reliabilities are given in Table VII.

It may be inferred from the small values of $p_i$ that the zero hypothesis, *i.e.* the hypothesis that there are no interactions, is not valid.

TABLE VII

| The coefficients $\bar{a}_i$ and the probabilities $p_i$ for the differences between PMg- and P-plots | | | |
|---|---|---|---|
| Interactions between magnesium treatment and: | $\bar{a}_i$ | $s\bar{a}_i$ | $p(a'_i = 0)$ |
| magnesia content | 0.51 | 0.23 | 0.018 |
| pH | 1.37 | 0.21 | 0.000 |
| potassium number | 1.37 | 0.32 | 0.000 |

The same holds for the interactions between magnesium treatment and the various soil factors when, besides magnesium, potassium is added. However, there is again no influence of the potassium number; in Figure 6 this is reflected in the fact that the two curves run parallel to each other. The statistical reliability is given in Table VIII.

TABLE VIII

| The coefficients $\bar{a}_i$ and the probabilities $p_i$ for the differences between PKMg- and PK-plots | | | |
|---|---|---|---|
| Interactions between magnesium treatment and: | $\bar{a}_i$ | $s\bar{a}_i$ | $p(a'_i = 0)$ |
| magnesia content | 1.00 | 0.29 | 0.000 |
| pH | 0.51 | 0.20 | 0.010 |

The interactions between potassium treatment and the various soil factors are far less conspicious when, besides potassium, magnesium has been applied. The only influence that can be demonstrated with statistical reliability is that of the pH, as appears from Table IX. It will be seen that this differs from the result found when the effect of a potassium treatment without magnesium was investigated. The explanation is that in that case, according to Table VI, no influence of the pH could be demonstrated.

TABLE IX

| The coefficients $\bar{a}_i$ and the probabilities $p_i$ for the differences between PMgK- and PMg-plots | | | |
|---|---|---|---|
| Interactions between potassium treatment and: | $\bar{a}_i$ | $s\bar{a}_i$ | $p(a'_i = 0)$ |
| magnesia content | 0.61 | 3.47 | 0.74 *) |
| potassium number | 0.62 | 1.40 | 0.57 *) |
| pH | 0.96 | 0.33 | 0.005 |

*) Extrapolated from the graph.

Besides the interaction between the various treatments and the soil factors there are also interactions between the soil factors themselves. It has been said previously that it is possible to approach

these interactions in a different way. For this purpose the data must be divided into two groups, the above given analysis being then made on each group. Through lack of space only the results for the P-plot are given.

The data were first classified according to the potassium contents of the soil. The first group contains these cases with a potassium number below 20 and a mean potassium number of 16.5; the second group contains those cases with a potassium number above 23 and a mean of 30.5. The result of this method of presentation is partly shown in Figure 9. There is a distinct interaction between potassium

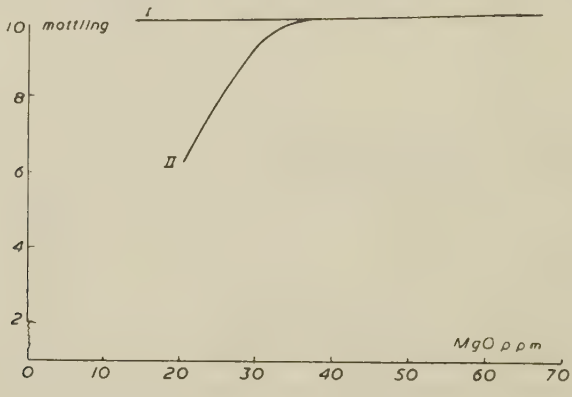


Fig. 9. The relation between the MgO-content of the soil and the degree of mottling; I at low and II at high K-number.

number and magnesia content: in the case of little potassium even a low magnesia content produces no mottling; a high potassium number increases mottling. Moreover, there is an interaction between pH and potassium number. A difference from the last result is that now in the case of a low potassium status there is still an unfavourable effect of a low pH. A shift of the limiting value to the left in only apparent if the potassium number is low. This shift amounts to half a pH unit per 10 potassium number units.

The statistical reliability of the main effects found is shown by the data in Table X.

The influence of the magnesia content in the case of a high potassium status is not reliable; there is only a slight indication of this. This may be due to the fact that the number of degrees of freedom, remaining after the division, is too small.

TABLE X

The coefficients $\bar{a}_i$ and the probabilities $p_i$ for the P-plot in cases of low and high potassium status

| Factor | $\bar{a}_i$ | $s\bar{a}_i$ | $p(a'_i = 0)$ |
|---|---|---|---|
| pH and low potassium status . . . . . | 0.99 | 0.12 | 0.000 |
| magnesia content and high potassium status. | 0.55 | 0.41 | 0.125 |
| pH and high potassium status . . . . . | 0.83 | 0.40 | 0.045 |

The interaction between the magnesia content and pH is shown in Figure 10. The data have again been divided into two groups. The first group consists of cases with a pH lower than 4.80 and with a mean pH of 4.40; the second group contains those cases with a high pH and a mean of 4.95.

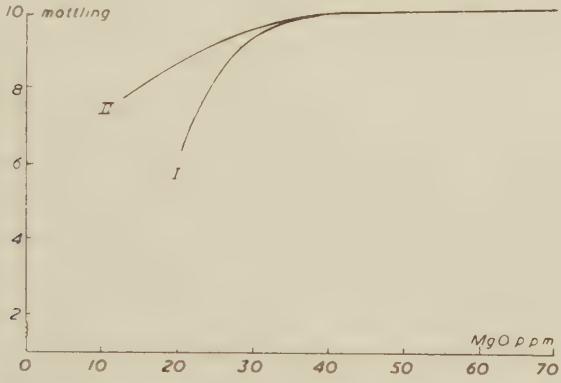


Fig. 10. The relation between the MgO-content of the soil and the degree of mottling; I at low and II at high pH.

The effect of the magnesia content is considerably influenced by the pH; a low pH promotes the symptoms. From Figure 5 it appeared that the approximate limiting value for the pH is 4.90. The mean pH of the second group in Figure 10 is 4.95. This shows that complete prevention of mottling with a still higher pH and a low magnesium status is impossible. This corroborates the result shown in Figure 7. There is no shift in the limiting value with a change in the pH. This confirms the results of Castenmiller[1]) and Sluijsmans[15]).

Moreover, there is an interaction between potassium number and pH. This result has not been shown however; it was referred to

earlier when this interaction could be demonstrated in a different way (page 282).

The statistical reliability is shown by the data of Table XI.

TABLE XI

The coefficients $\bar{a}_i$ and the probabilities $p_i$ for the P-plot in the case of low and high pH

| Factor | $\bar{a}_i$ | $s_{\bar{a}_i}$ | $p(a'_i = 0)$ |
|---|---|---|---|
| magnesia content and low pH | 1.25 | 0.40 | 0.008 |
| potassium number and low pH | 2.48 | 1.05 | 0.018 |
| magnesia content and high pH | 1.43 | 0.72 | 0.038 |
| potassium number and high pH | 0.82 | 0.55 | 0.080 |

The influence of the potassium content in the case of a high pH is not indicated with sufficient reliability. This result was expected; an antagonistic effect of potassium decreases in the case of a better magnesium supply (high pH).

## MOTTLING AND MAGNESIUM SUPPLY

On the ground of the fact, that mottling in oats is caused by an insufficient Mg-supply, it may be expected that the magnesia content of the leaves is more or less determined by the same factors (and in the same way) as is the degree of mottling. Moreover, a relation between the degree of mottling and the magnesia content may also be expected.

The content figure have been treated in the same way as the mottling figures. The magnesia content of the soil, the pH and the potassium number are again taken as independent factors. When the crop was sampled, the stages of development in the various experimental fields varied a great deal. Besides the date of sowing, other variables may also have determined the stages of development when the samples were taken. It is desirable to eliminate any influence of these differences in development on the MgO-content. Like other investigators we have chosen the nitrogen content of the leaves as a measure of the development; this has been included as the fourth independent factor in the analysis. The N-content has been correlated with various factors, such as the pH and date of sowing.

Before discussing the results, we give first the influence of the diverse treatments on the MgO-content of the leaves, averaging the

39 trial plots. In Table XII are presented the mean differences between the various trial plots with the two-tailed probability $p_i$.

TABLE XII

Increase of the MgO-content of leaves due to P- and K-treatments with the probabilities $p_i$

| Treatment | increase | $p_i$ |
|---|---|---|
| Potassium without addition of magnesium. . . . . | 0.0095 | 0.002 |
| ,, with addition of magnesium . . . . . | 0.0005 | 0.75 |
| Magnesium without addition of potassium . . . . | 0.0208 | 0.000 |
| ,, with addition of potassium . . . . . | 0.0118 | 0.000 |
| Potassium and magnesium . . . . . | 0.0213 | 0.000 |

It would appear that not only the magnesium treatment but also the potassium treatment has increased the MgO-content. In both cases the effect is comparatively small but nearly all increases are statistically reliable; the probabilities are smaller than the 0.05 level of significance. The only exception is the potassium treatment when magnesium has also been added.

The increase in the MgO-content of the leaves by the potassium treatment is remarkable for two reasons. In the first place, no antagonistic effect of the potassium addition on the magnesia content is apparent and, in the second place, potassium treatment actually tends to increase the degree of mottling as has been shown in the preceding section. An acceptable explanation for this seemingly anomalous situation might be that the antagonistic effect of the potassium is not apparent in the amount of magnesium absorbed but appears in the symptoms in the leaves because the rise in the $K_2O$-content due to potassium treatment has probably been relatively greater than the increased MgO-content. This will be referred to later on.

Those factors will now be discussed, which prove to be related to the MgO-content of the leaves. It should be noted that the differences in level between the curves found is caused by differences between plots in the mean MgO-content of the leaves; here again more attention must be paid to the form of the curve than to its level.

The influence of the magnesia content of the soil on the content of the leaves is illustrated for the various plots in Figure 11. If these effects are compared with those on mottling, three things are notice-

able. First, that in case of high magnesia contents of the soil a so-called luxury uptake of magnesium is apparent; with adequate magnesium the curves still show an upward trend. The second notable fact is the correspondence in location of the region of maximum

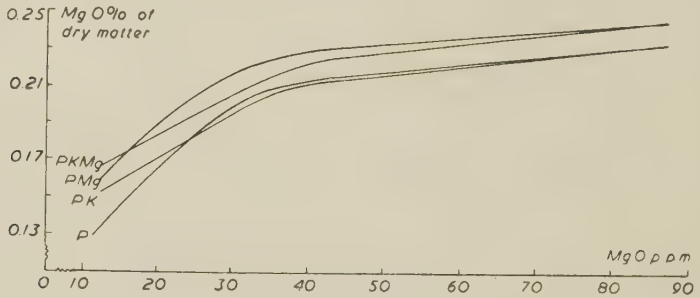


Fig. 11. The relation between the MgO-content of the soil and the MgO-content of the plant.

curvature; this part of the curve in both cases lies approximately at a content of 25–30 ppm. The third notable point is the clear difference in the response to magnesium treatment. A magnesium treatment causes mottling to disappear almost completely so that there is no longer any influence of the MgO-content of the soil. In the case of the MgO-content of the leaves the influence of the MgO-content of the soil still remains. The data concerning the statistical reliability are shown in Table XIII. The effects are all statistically reliable.

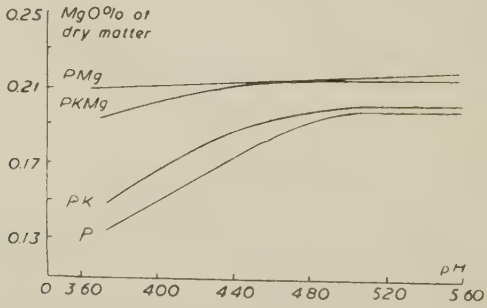


Fig. 12. The relation between the pH of the soil and the MgO-content of the plant.

The response in the MgO-content of the leaves to differences in pH, as shown in Figure 12 for the various plots however, differs

from that due to the MgO-content of the soil. The effects appear similar to those of the pH on mottling. The influence of pH (P- and PK-plots) disappears when the limiting value exceeds 4.80 approximately; above this value the curves are horizontal. It should be remembered that the limiting value found for mottling was also 4.80. Another difference is that there is now a clear influence of the magnesium treatment on the form of the curve. For details as to the reliability of these results see Table XIII. From this it appears that the pH effect in the case of the PMg-plot was considerably underestimated; $\bar{a}$ is 3.33, so that the scale must be multiplied by the factor 1.3.33. The effects of pH are all statistically reliable, except those for the PKMg-plot.

From the above there appears to be a clear difference in response in the MgO-content of the leaves to the magnesium status and the pH of the soil. If allowance is made for the response in mottling to a modification of these two factors, we get the impression that the nature of the effect of pH is different to that of the magnesia content of the soil. Without further investigation nothing more definite can be said, but we wonder whether, from what has already been discussed, it may be concluded that the influence of the pH is only of an inhibitory nature. This inhibitory influence is no longer apparent when the pH is high or when a supplementary magnesium treatment is applied. This inhibitory effect may be due to stunted growth of the root system or perhaps of a different physiological or soil-chemical nature (see introduction).

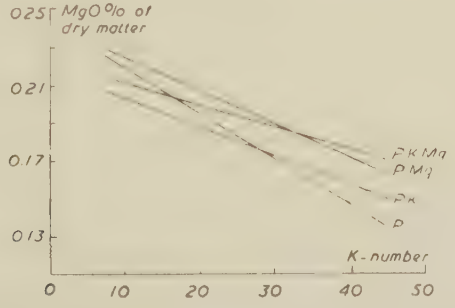


Fig. 13. The relation between the K-number of the soil and the MgO-content of the plant.

The influence of the potassium number of the various plots, as shown in Figure 13, and, according to Table XIII, all statistically reliable,

calls for little comment. The general picture is in agreement with the effect of the potash number on the appearance of mottling. The lower significance in the case of the potassium treatment — also found in the case of mottling — is corroborated; the slopes of the two curves are less steep. The effect of a potassium treatment in increasing the MgO content of the leaves, referred to above, is, however, not in agreement with this result.

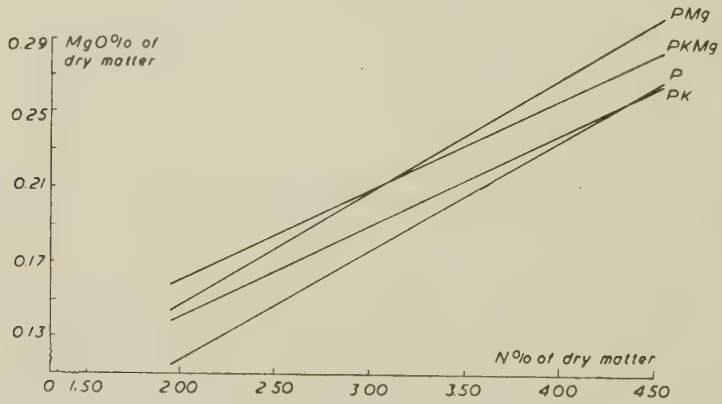


Fig. 14. The relation between the N-content of the plant and the MgO-content of the plant.

The factor exercising the greatest influence on the MgO-content proved to be the N content of the leaves. Figure 14 shows this influence for the four trial plots. It appears that a change in the N-content of 1% is associated with a change in the MgO-content of the leaves of 0.06%; in view of the variation which occurs, this is indeed a considerable effect. The older the crop, the lower the MgO-content proves to be. The effects of the N-content are statistically reliable as is shown in Table XIII.

Finally we investigated the significance of the differences between the subplots, shown in Figure 11, 12, 13 and 14. Our aim was to find out the statistical reliability of these differences (interactions). As before, the differences between two plots (each time) were taken as dependent factors and these were represented statistically. Most differences in the form of the curves were proved to be accidental. As exceptions to this are the interactions between magnesium treatment and pH. Consequently there is sufficient reason to regard

TABLE XIII

The coefficients $\bar{a}_i$ and the probabilities $p_i$ for the trial plots, P, PK, PMg and PKMg

| Plot | Factor | $\bar{a}_i$ | $s\bar{a}_i$ | $p(a'_i = 0)$ |
|---|---|---|---|---|
| P | magnesia content | 0.79 | 0.21 | 0.003 |
| | pH | 1.04 | 0.32 | 0.005 |
| | K-number | 0.71 | 0.24 | 0.004 |
| | N % leaves | 0.99 | 0.15 | 0.000 |
| PK | magnesia content | 0.88 | 0.18 | 0.000 |
| | pH | 1.19 | 0.33 | 0.004 |
| | K-number | 0.71 | 0.26 | 0.015 |
| | N % leaves | 1.05 | 0.12 | 0.000 |
| PMg | magnesia content | 1.19 | 0.22 | 0.000 |
| | pH | 3.33 | 1.73 | 0.049 |
| | K-number | 1.06 | 0.27 | 0.002 |
| | N % leaves | 1.00 | 0.13 | 0.000 |
| PKMg | magnesia content | 0.84 | 0.35 | 0.000 |
| | pH | 0.88 | 0.72 | 0.160 |
| | K-number | 0.87 | 0.34 | 0.019 |
| | N % leaves | 1.05 | 0.16 | 0.000 |

the differences in response to the pH between the P- and PMg-plots and between the PK- and PKMg-plots as real.

At the beginning of this section we mentioned the possibility of an expected relation between the degree of mottling and the MgO-content of the leaves.

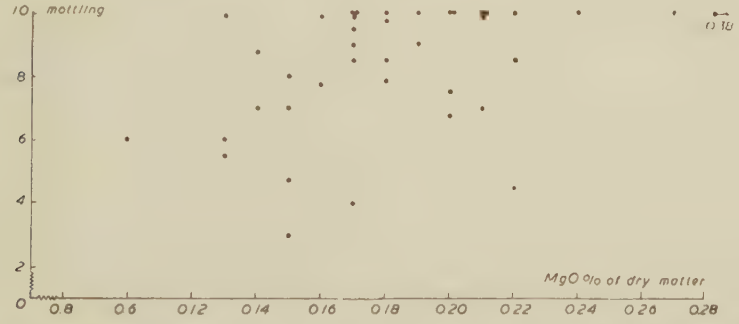


Fig. 15. The relation between the MgO-content of the plant and the degree of mottling; without correction for the N-influence.

The mottling figures *e.g.* for the P-plot when plotted against the corresponding MgO-contents show a poor relation (Figure 15). How-

ever, the MgO-content was found to be closely related to the N-content. It is reasonable to take this relation into account in studying the significance of the MgO-content for the appearance of mottling, because the mottling symptoms change as the plant gets older. Therefore all data have to be reduced to an equal nitrogen level. This is done by correcting the MgO-contents for the effects shown in Figure 14 to N-content of 2.95%. The mottling figures now show a very clear relation with these corrected MgO-contents (Figure 16).

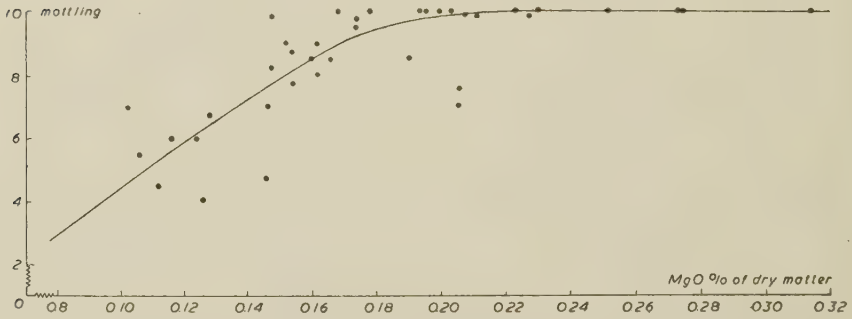


Fig. 16. The relation between the MgO-content of the plant and the degree of mottling; after correction for the N-influence.

A similar treatment of the PK-plot data gives the relation shown in Figure 17, in which, for comparison, the relation found in Figure 16 is also presented. Both curves indicate the relation at a nitrogen level of 2.95%.

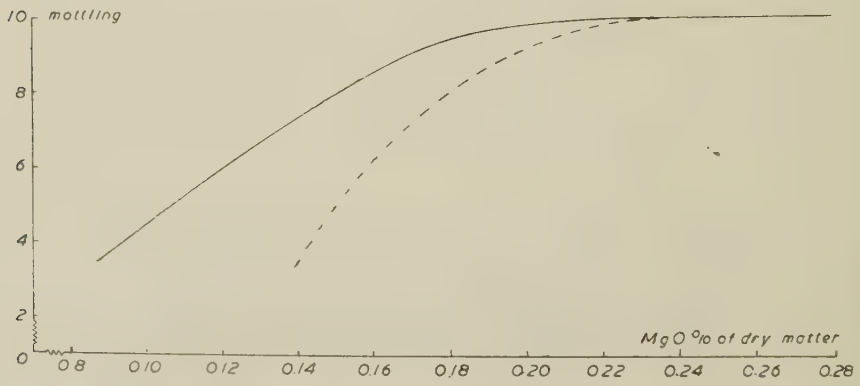


Fig. 17. The relation between the MgO-content of the plant and the degree of mottling; for P-treatment and PK-treatment (dotted line).

The limiting value for the MgO-content of the leaves in the case of this N-content, below which mottling appears without potassium treatment, approximates to an MgO-content of 0.20%. It is clear that, apart from the unknown weather conditions, no absolute significance can be attached to this value. According to the nitrogen level, *i.e.* the stage of development, the limiting value will vary; taking into account the rectilinear nature of the nitrogen effect, the variation may be fixed at 0.06% per 1% N. The higher the N-content of the crop the higher is the limiting value.

The N-content is not the only factor affecting the limiting value. Figure 17 shows that the $K_2O$-content of the leaves is also significantly concerned. With the addition of 120 kg $K_2O$ per hectare the limiting value of an average shows an upward change of about 0.02. The $K_2O$-content of the leaves was not determined, so that the increase in this content with the potassium treatment is unknown.

The difference in situation and in slope between the two curves showing the relation between mottling and MgO-content with and without potassium treatment, demonstrates an antagonistic action between potassium and magnesium. The degree of mottling increases when, at the same MgO-content, the potassium supply and therefore presumably also the $K_2O$-content, is higher; the lower the MgO-content, the greater is the effect.

Accordingly in giving a limiting value for the MgO-content of the leaves, taking as the norm the appearance or non-appearance of mottling, not only the nitrogen content but probably also the $K_2O$-content of the leaves must be taken into account.

It would not have been surprising if the relation (not yet discussed) between mottling and MgO-content of the leaves for the PMg- and PKMg-plots could have been represented by the same curves as for the P- and PMg-plots, respectively. This might be expected, if the mottling picture is determined by the amount of MgO per gram dry matter (after N-correction). The curves found, which are omitted for the sake of brevity, however, prove to be higher than those shown in Figure 17; the difference, caused by the potassium treatment, is again apparent, just as in the case of the plots without magnesium treatment.

The results discussed in this section enable us to test the correctness of what was found in the preceding section.

By means of the relations existing between the various soil factors and the MgO-content of the leaves and between the MgO-content of the leaves and mottling, we now can compute the influence which the soil factors exercise on the degree of mottling, provided the relation (not subjected to N-correction) is employed between mottling and MgO-content of the leaves. This is necessary because in the diagrams in which mottling is plotted against the various soil chemical factors, no allowance is made for the stage of growth. These computations made for some trial plots, lead to a satisfactory agreement between the results.

## CONCLUSIONS

The results obtained clearly show that the extraction and analytic methods employed are suited for the determination of the amount of magnesium in the soil which is available to the plant. It was found that besides the magnesia content of the soil, other factors influence the availability to the plant. Under the present conditions these proved to be the pH, the potassium status and the potassium treatment.

The great significance of judging the crop according to the degree of mottling is evident from the results obtained. Mottling is more susceptible to a change in the magnesium supply than is the yield of the crop. The responses are in large measure apparent within a mottling range of 7.5 to 10; only below mottling figures 7–7.5 a decrease in yield was found.

The result may show that we are justified in concluding that mottling in oats is due to an insufficient MgO-content or too high a ratio of potassium to magnesium in the leaves, in which the stage of development of the plant also plays a part. According to this investigation the MgO-content of the leaves is determined by the MgO-content of the soil, the magnesium treatment, the pH, the potassium supply and the stage of growth of the crop.

## SUMMARY

The disease of oats and other cereals, known in the Netherlands as "Hooghalen disease", is characterized by a more or less striking degree of mottled colouring of the plant, resulting from the "curdling" of the chlorophyll. At worst the plant becomes yellow-coloured throughout. Slight

symptoms are slightly or not at all associated with lower yields; serious symptoms result in considerable losses of the crop.

In the literature on the subject reference is made to various factors affecting the appearance of the disease, the most important of which are the magnesium status of the soil, the pH, the potassium supply, the humus content and the form of nitrogen. According to several investigators the real cause is magnesium deficiency.

In the present investigation we have endeavoured to determine quantitatively the significance of some factors in the degree of mottling. The assessment was based on visible symptoms, which are more suitable for an investigation of this kind than are the yields, especially as a slightly mottled colouring is not necessarily associated with lower yields. For an easy representation of the data the various "syndromes" (symptom complexes) were marked 1 to 10 inclusive. Low marks were awarded for serious symptoms, and a completely sound crop was marked 10. With the aid of this scale assessments were made on a young crop of oats (height: 10–30 cm) growing on a number of experimental fields on a sandy soil, treated with K, P, PK (twice), PMg or PKMg (each field has 6 subplots). The degree of mottling was correlated by a numeric-graphical method, with the factors, MgO-content of the soil (determined in an 0.5 *N* NaCl-extract), pH–KCl, K-number (determined in an 0.1 *N* HCl extract) and humus content. The results are presented in Figures 3–10. The tables give the correction factors $\bar{a}_i$ and the statistical reliability $p_i$ of the findings.

Shortly after judging the oats, leaf samples were taken, and their MgO- and N-contents were determined. The N-content served as a measure of the stage of growth. The MgO-content was correlated with the same factors as in the case of the mottling symptoms. The significance of the N-content was also studied. The results of these computations are shown in Figures 11–14.

Finally the relation was studied between the syndromes and the MgO content of the crop (Figures 15–17).

The most important conclusions from this investigation were as follows:

*Figures 3–10.* The degree of mottling is related to the MgO-content of the soil, the K-number of the soil, the Mg-treatment and the K-treatment. The humus content showed no relation to the syndrome.

The nature of the influences of the MgO-content and of the pH of the soil is in both cases characterized by a rising to a maximum with limiting values at 35–40 ppm and 4.8 respectively. The influence of the K-number of the soil is evident from the linear nature of the curve. Conditions for serious disease symptoms are thus simultaneous occurrence of low MgO-content, low pH and high K-number of the soil.

A treatment of approximately 40 kg MgO per hectare considerably reduced the mottled colouring, the influences of the factors MgO-content of the soil and pH being almost completely counteracted; the influence of the K-number was also decreased. By applying a larger amount of MgO the

influence of pH can be completely eliminated. The value of the magnesium added is lower than that which is already present in the soil. A treatment of 120 kg $K_2O$ per hectare aggravates the disease symptoms especially if no magnesium is applied. The influence of the potassium treatment is greatest in case of a low MgO-content of the soil; the pH has some influence on the effect of the K-treatment only if at the same time, Mg is added. K-treatment considerably diminishes the influence of the K-number of the soil.

The limiting value for the MgO-content of the soil depends little on the pH, but shows a downward trend if the K-number increases.

*Figure 11–14.* The MgO-content of the crop is related in a similar way to the same factors as in the case of mottling. Furthermore, it is shown that the MgO-content decreases with increasing age of the plant. A high magnesia content of the soil causes a luxury uptake of magnesium whereas a high pH does not. The significance of the pH for the magnesium supply of the plant is probably of an inhibitory nature, most associated with root development.

By applying magnesium at 40 kg MgO per hectare, the MgO-content of the crop is increased by 0.01–0.02%. The MgO-content is also increased by the potassium treatment but this increase is small and does not amount to more than 0.01%.

*Figure 15–17.* A clear relation between mottling and MgO-content of the leaves is only found if the MgO-contents are corrected to the same N-content The limiting value for the MgO-content of the leaves below which mottling appears without K-treatment is approximately 0.20% (at a N-content of 2.95%). The value shows an upward trend as the N-content increases and consequently as the age of the crop decreases.

The results of the investigation may justify the assumption that mottled colouring in oats results from an insufficient MgO-content or from too much potassium in relation to magnesium in the leaves, in which the N-content should also be taken into account.

## RÉSUMÉ

La maladie de l'avoine et des autres céreales, connue aux Pays-Bas sous le nom "Hooghalense ziekte" (c.-à-d. maladie de Hooghalen ou carence de magnésium) est caractérisée par la séparation plus ou moins marquée de la chlorophylle dans les feuilles, donnant à la plante un aspect tigré. Dans les cas les plus graves la plante peut même jaunir complètement, ce qui donne lieu à des dépressions de rendements très sensibles, tandis que ceci ne se produira pas ou presque pas lorsqu'il s'agit d'une légère apparition de cette maladie.

Dans la littérature plusieurs facteurs influençant l'apparition de cette maladie sont nommées. Les plus importantes en sont le pH, l'approvision-

nement en potasse, la teneur en magnésium (et en humus) du sol et de la forme sous laquelle est administrée la fumure azotée.

Selon plusieurs auteurs la cause proprement dite est une question de carence de magnésium.

Dans la présente recherche nous avons essayé d'approfondir quantitativement la signification de quelques facteurs influençant l'intensité d'apparition des symptômes de cette maladie. Ceci a été fait à l'aide des symptômes visuellement perceptibles, plus commodes à manipuler dans une telle recherche, où, dans les cas légers, l'apparition de cette maladie ne va pas nécessairement de paire avec des diminutions de rendements. Pour une maniement plus facile des données, les différents degrés d'intensité de la maladie furent appréciés à l'aide d'une note entre 1 et 10. Les cas les plus graves obtiennent les chiffres les plus bas, tandis que les cultures saines reçoivent l'appréciation 10. A l'aide de cette échelle, des jeunes cultures d'avoine (longueur 10–30 cm) sur des champs d'expériences sur sols sablonneux furent taxées. Ces champs d'essais comprenaient les formules de fumures suivantes: K, P, PK (2×), PMg et PKMg. Les chiffres avec lesquels le degré de tigrage fut caractérisé, ont été mis en relation par formule de fumure, selon la méthode numérique-graphique, avec les facteurs teneur en MgO du sol (déterminée dans un extrait de NaCl, 0.5 *N*), pH–KCl, teneur en potasse (déterminée dans un extrait de HCl, 0.1 *N*), et en humus du sol. Les résultats sont mentionnés dans les figures 3–10. Les tabelles mentionnent le facteur de correction $\bar{a}_i$ et le degré de signification statistique $p_i$.

Peu après la taxation de l'avoine des échantillons foliaires furent prélevé pour la détermination des teneurs en MgO et en azote, cette dernière devant surtout servir comme norme de la phase de développement des différentes cultures. La teneur en MgO a été mis en relation avec les mêmes facteurs utilisés dans les rapports avec le degré de tigrage des feuilles (fig. 11–14).

En suite nous avons encore essayé de trouver une relation entre le degré de tigrage et la teneur en MgO des feuilles (fig. 15–17).

Les conclusions les plus importantes de cette recherche sont les suivantes:

*Fig. 3–10.* Le degré de tigrage dépend de la teneur en MgO du sol, le pH, la teneur en potasse et de la fumure magnésienne et potassique. La teneur en humus n'exerçait pas d'influence sur l'apparition des symptômes de la maladie. L'influence de la teneur en magnésium du sol et du pH est caracterisée dans les deux cas par un courbe à maximum dont les valeurs limites se trouvent respectivement à 35–40 ppm et 4.8, tandis que la relation avec la teneur en potasse du sol est linéaire. La présence simultanée d'un teneur en MgO du sol bas, d'un pH bas et d'un teneur en potasse du sol élevé, donne lieu à l'apparition de symptômes de carence magnésienne très graves.

Une fumure avec 40 kg MgO/ha réduit considérablement le tigrage des feuilles. L'influence des facteurs MgO du sol et pH est alors presque complètement éliminée, celle de la teneur en potasse du sol affaiblie. En utilisant une plus forte dose de MgO l'influence du pH du sol peut être com-

plètement annulées. La valeur du magnésium donné comme engrais est moindre que celle se trouvant au sol.

Une fumure de potasse de 120 kg $K_2O$/ha aggravera surtout le tigrage lorsqu'on omet de donner également une fumure de magnésium. L'influence d'une fumure potassique est la plus grande lorsque la teneur en MgO du sol est bas. Le pH n'a que quelque influence sur l'effet d'une furmure potassique si l'on donne en même temps une fumure magnésienne. Par une fumure potassique de la teneur en potasse du sol est considérablement affaiblie.

Les valeurs limites de la teneur en MgO du sol ne dépendent que très peu du pH, mais se déplacent vers en bas à mesure que la teneur en potasse du sol devient plus petite.

*Fig. 11–14.* La teneur en MgO des feuilles dépend des même facteurs et à peu près de la même façon comme trouvée pour le tigrage. En plus il apparaît qu'il existe une relation étroite entre la teneur en MgO et celle de l'azote dans les feuilles; à mesure que la plante est plus développée, la teneur en MgO est plus basse.

Une haute teneur en MgO au sol occasionne une consommation de luxe de la magnésie, un pH élevé pas. L'importance du pH dans l'approvisionnement en magnésium des plantes réside probablement dans le rôle de frein qu'il joue; en première instance il faudra penser ici aux possibilités de développement du système radiculaire des plantes.

Par une fumure magnésienne de 40 kg MgO/ha, la teneur en MgO des feuilles montera de 0.01–0.02%; une fumure potassique fait également quelque peu monter cette teneur. Cette hausse est cependant moins marquée et ne dépassera pas le 0.01%.

*Fig. 15–17.* Une relation étroite entre le degré de tigrage et la teneur en MgO des feuilles n'apparaîtra seulement que si l'on tient compte avec l'âge des plantes en reduisant tous les teneurs en MgO à la même teneur d'azote des feuilles. La valeur limite de la teneur en MgO des feuilles sous laquelle apparaîtra, sans fumure potassique, des symptômes de tigrage, se trouve à 0.20% de MgO (teneur en azote 2.95%). Avec une fumure potassique cette valeur limite se trouvera de 0.02% plus haute. La valeur limite se déplacera vers en heut à mesure que la teneur en azote est plus haute, donc à mesure que la plante est plus jeune.

Les résultats de cette recherche donnent suffisamment de preuves pour pouvoir admettre que le tigrage de l'avoine est la conséquence d'une teneur en MgO insuffisante ou d'un rapport trop élevé entre les teneurs en potasse et en magnésie dans les feuilles, dans quel rapport la teneur en azote joue également un rôle.

## ZUSAMMENFASSUNG

Die Krankheit von Hafer und anderen Getreidearten, in den Niederlande bekannt als "Hooghalense ziekte" (d.h. Hooghalensche Krankheit oder

Sauerkrankheit, bzw. Magnesiummangelchlorose), wird gekennzeichnet durch ein mehr oder weniger Zusammenhaufen des Chlorophylls, wodurch die Blätter tigerähnliche Verfärbungen bekommen und in den schlimmsten Fällen selbst ganz vergilben. Bei einer schwachen Erkrankung werden nur wenig oder selbst gar keine Ertragsverluste festzustellen sein; in sehr schlimmen Fällen sind die Ertragsminderungen aber sehr erheblich.

Die Literatur nennt verschiedene Faktoren, die das Entstehen dieser Mangelerscheinung zu Grunde liegen. Die wichtigsten sind der Magnesium- und Humusgehalt der Böden, die Kaliversorgung der Pflanze, die Bodenreaktion und die Form der Stickstoffdüngung. Verschiedene Förscher geben als Grundursache Magnesiummangel im Boden an.

In der vorliegenden Forschung haben wir versucht die Bedeutung verschiedener Faktoren auf den Grad des Krankheitsbefalles kwantitativ zu erfassen. Dieses geschah unter Zuhilfenahme der visuel ersichtbaren Symptomen die sich besser für solche Untersuchungen gebrauchen lassen als Ertragsbestimmungen, gerade weil ein schwacher Krankheitsbefall nicht immer parallel geht mit einer Ertragsminderung. Zu bequemer Hantierung der verschiedenen Daten wurden die Krankheitsbilder bewertet mit Ziffern zwischen 1 und 10. Ein ernsthafter Krankheitsbefund wurde mit niedrigen Zahlen bewertet, gesunde Gewächse erhielten 10. Unter Zuhilfenahme dieses Skalas wurden junge Haferkulturen (10–30 cm hoch) auf verschieden Versuchsfeldern auf Sandböden beurteilt. Diese Versuchsfelder umfassten die folgenden Objekte: K, P, PK (2 ×), PMg und PKMg. Die Bewertungsziffern wurden je Objekt, mittels einer numerisch-graphischen Methode mit den folgenden Bodenfaktoren in Beziehung gebracht: MgO-Gehalt des Bodens (bestimmt in 0.5 *N* NaCl-Extrakt), Kaligehalt des Bodens (bestimmt in 0.1 *N* HCl-Extrakt), pH–KCl und Humusgehalt. Die Resultate sind ersichtlich aus den Figuren 3 bis 10. Die Tabellen geben einen Korrektionsfaktor $\bar{a}_i$ und den statistischen Sicherheitsfaktor $p_i$.

Kurz nach der Bewertung des Hafers wurden Gewächsmuster entnommen und auf MgO- und N-Gehalt (als Mass für das Entwicklungsstadium der untersuchten Gewächse) untersucht. Der MgO-Gehalt wurde auf ähnliche Weise wie mit den Tigerungbewertungsziffern geschah, mit den unterschiedenen Bodenfaktoren in Beziehung gebracht, wobei überdies auch die Bedeutung des N-Gehaltes noch untersucht wurde (Fig. 11–14).

Schliesslich wurde noch die Beziehung zwischen Krankheitsbild und MgO-Gehalt der Blätter untersucht (Fig. 15–17).

Die wichtigsten Ergebnisse sind die folgenden:

*Fig. 3–10.* Der Grad des Auftretens der Krankheit hängt zusammen mit dem MgO-Gehalt des Bodens, dem pH-Wert, dem Kaligehalt des Bodens und der Düngung mit MgO und Kalium. Zwischen Humusgehalt und Krankheitsbild wurde keine Beziehung gefunden.

Die Art der Einflüsse des MgO-Gehaltes und des pH-Wertes des Bodens kennzeichnete sich in beiden Fällen durch eine Maximumkurve mit Grenzwerten bei bzw. 35–40 ppm und 4.8. Der Einfluss des Kaligehaltes des Bo-

dens war lineärer Art. Bedingung für das Auftreten ernsthafter Krankheitsbilder ist das gleichzeitig im Boden Vorkommen von niedrigen MgO-Gehalten, niedrigen pH-Werten und höhen Kaligehalten.

Eine Magnesiumdüngung nach 40 kg MgO pro Hektar hat eine erhebliche Herabsetzung des Tigerungsgrades zur Folge. Der Einfluss des MgO-Gehaltes des Bodens und des pH-Wertes wurde hierdurch praktisch ganz ausgeschaltet, der Einfluss des Kaligehaltes erheblich abgeschwächt. Durch Anwendung eines grösseren Quantums MgO kann der Einfluss des pH-Wertes ganz aufgehoben werden.

Das als Dünger gegebene Magnesium ist in Wert geringer als desjenigens das sich schon im Boden befindet.

Wenn keiner Magnesiumdünger wird gegeben, wird das Krankheitsbild durch eine Kalidüngung nach 120 kg pro Hektar verstärkt. Der Einfluss der Kalidüngung ist am grössten bei einem niedrigen MgO-Gehalt des Bodens; der pH-Wert hat nur einen geringen Einfluss auf diesen Kalidüngungseffekt wenn gleichzeitug auch eine Magnesiumdüngung gegeben wird. Der Einfluss der Kaligehaltes des Bodens wird stark herabgesetzt durch eine Kalidüngung.

Der Grenzwert des MgO-Gehaltes im Boden hängt nur wenig ab von dem pH-Wert, aber verschiebt sich nach unten wenn der Kaligehalt des Bodens niedriger wird.

*Fig. 11–14.* Der MgO-Gehalt der Blätter steht ungefähr auf gleichartige Weise in Beziehung zu denselben Faktoren wie diese schon gefunden wurden beim Zusammenhang mit der Tigerung. Ausserdem besteht eine starke Korrelation zwischen MgO- und N-Gehalt der Blätter. Je nachdem die Pflanze älter ist, wird der MgO-Gehalt niedriger. Ein hoher MgO-Gehalt des Bodens führt zu einem Luxuskonsum an Magnesium, ein hoher pH-Wert nicht. Die Bedeutung des pH-Wertes für die Magnesiumversorgung der Pflanzen ist wahrscheinlich von hemmender Art; im ersten Instanz soll dabei gedacht werden an die Möglichkeit der Entwickelung des Wurzelsystems.

Durch eine Magnesiumdüngung von 40 kg MgO pro Hektar wird der MgO-Gehalt der Blätter von 0.01–0.02% gesteigert; durch eine Kalidüngung ebenfalls aber in geringerer Masse und nicht mehr als 0.01%.

*Fig. 15–17.* Eine deutliche Beziehung zwischen Tigerung und MgO-Gehalt der Blätter wird nur gefunden wenn der MgO-Gehalt auf gleichen N-Gehalt reduziert wird. Der Grenzwert für MgO-Gehalt in Blättern wobei ohne Kalidüngung, Tigerung auftritt, liegt bei 0.20% MgO (und 2.95% N). Mit Kalidüngung liegt der Grenzwert um 0.02% höher. Der Grenzwert verschiebt nach oben je nachdem der N-Gehalt höher liegt, d.h. die Pflanze jünger ist.

Die Resultate dieser Forschung geben genügend Beweise um anzunehmen dass Tigerung im Hafer verursacht wird durch einen zu niedrigen MgO-Gehalt des Bodens oder ein zu weites Verhältnis zwischen Kali- und Magnesiumgehalt im Blatt, wobei auch der N-Gehalt der Pflanze eine Rolle spielt.

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# THE EFFECT OF WASHING AND A LEAD ACETATE SOIL TREATMENT ON THE PHOSPHORUS CONTENT OF BARLEY AND TOMATO ROOTS

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In a recent article Russell and Adams [4]) describe a method designed to reduce the loss of phosphate which may occur from plant roots washed to remove soil or nutrient solution. In their experiments they cut the plant tops at soil level and then added 15% basic lead acetate solution to the soil, 24 hr prior to root washing. They found the phosphate content of untreated roots to be 82.5% of that of those treated with basic lead acetate (5% fiducial limit: $\pm$ 6.2). They refer to a paper [1]) in which we acknowledge a private communication from Dr. R. Scott Russell in which he recommended treatment of the soil with 10% commercial lead acetate prior to sampling to prevent loss of phosphate from roots during subsequent washing. In our experiments, however, we did not find any significant change between the P-contents of the control roots and those given this treatment. Therefore we did not use this method in our experiments [1]). Our decision was based on extensive tests, hitherto unpublished, but in view of the article by Russell and Adams we are now submitting a summary of the experimental results.

The experiments were designed to provide information on two points, (*a*) the effect of washing on the P-content of undamaged barley roots grown in nutrient solution, and (*b*) the effect of pretreatment with lead acetate on the P-content of tomato and barley roots grown in soil when subjected to the washing procedure recommended by us.

## EFFECT OF WASHING ON ROOTS GROWN IN NUTRIENT SOLUTION

Barley seedlings were raised in a complete nutrient solution and

after 7 to 10 days growth they were given a preliminary rinse in water and transferred to an automatic continuous-flow glass washing apparatus. Water entered at the bottom of the glass units, flowed over the roots and emptied via a side tube near the top of the apparatus. The rate of flow of water was regulated by lengths of capillary tubing adjusted so as to deliver approximately 550 ml of water per minute.

The control treatment consisted of three quick rinses in separate beakers of water to remove nutrient solution (total time less than 10 sec). In addition to this preliminary rinse other batches of seedlings grown in culture solutions (usually 15 per treatment) were subjected to varying washing times up to 20 min in the apparatus. To test the effect of washing on root adsorbed phosphate, as distinct from cell phosphate, batches of seedlings were washed for 20 min, re-immersed in nutrient solution for 5 sec und than rinsed in water for 10 sec as for controls. The roots from each seedling were treated as a single replicate. After drying, weighing and oxidation of organic matter with a mixture of nitric, perchloric and sulphuric acids, the total phosphorus was determined colorimetrically by the molybdenum blue method. The results of two washing experiments are given in Table I. Differences between treatment means and controls were tested for significance by the "*t*" test as described by Fisher[2]). It will be seen from Table I that there is no significant difference in the mean P-content of roots rinsed for less than 10 sec and those subjected to continuous washing for 20 min, during which time approximately 11 litres of water passed over the roots. It is unlikely that any significant loss of cell phosphate occurred in the first 10 sec, though we have no experimental data to prove this point.

Re-immersion of washed roots in a nutrient solution for a few seconds, followed by rinsing at various times, had no significant effect on the mean P-content of the roots.

In two instances total P, when expressed as a percentage of dry matter, was significantly higher than the control.

## EFFECT OF LEAD ACETATE TREATMENT ON THE P CONTENT OF ROOTS GROWN IN SOIL

### *Tomato*

Tomato seedlings were planted singly in 3″ pots containing soil

TABLE I. Effect of washing and re-immersion in nutrient solution on the $P_2O_5$ content of undamaged roots of barley seedlings grown in culture solution. Means of 15 replicates

| Treatment | Mean $P_2O_5$ content in mg | Difference from control | Value for "$t$" | Significance *$P$=0.05 **$P$=0.01 | Mean $P_2O_5$ as % dry matter | Difference from control | Value for "$t$" | Significance *$P$=0.05 **$P$=0.01 | Value of "$t$" for $P$=0.05 | Value of "$t$" for $P$=0.01 |
|---|---|---|---|---|---|---|---|---|---|---|
| A. Control — rinsing only (10 sec) | 0.905 | — | — | — | 5.933 | — | — | — | | |
| B. 20 min washing | 1.016 | +0.111 | 1.210 | N.S. | 6.440 | +0.507 | 1.745 | N.S. | 2.048 | 2.763 |
| C. 20 ,, ,, re-immersed in nutrient solution and rinsed as in A | 0.877 | —0.028 | 0.333 | N.S. | 6.093 | +0.159 | 0.340 | N.S. | 2.048 | 2.763 |
| A. Control — rinsing only (10 sec) | 0.414 | — | — | — | 3.116 | — | — | — | | |
| B. 5 min washing | 0.479 | +0.065 | 1.483 | N.S. | 3.454 | +0.338 | 2.125 | * | 2.048 | 2.763 |
| C. 10 ,, ,, | 0.544 | +0.130 | 2.389 | * | 3.627 | +0.511 | 3.756 | ** | 2.048 | 2.763 |
| D. 20 ,, ,, | 0.423 | +0.009 | 0.164 | N.S. | 2.922 | —0.194 | 1.384 | N.S. | 2.048 | 2.763 |
| E. 20 ,, ,, re-immersed in nutrient solution and rinsed as in A | 0.457 | +0.032 | 0.562 | N.S. | 3.172 | +0.056 | 0.350 | N.S. | 2.048 | 2.763 |

TABLE II. Effect of lead acetate treatment on the $P_2O_5$ content of roots of tomato grown in soil. Means of 10 replicates

| Treatment | Mean $P_2O_5$ content in mg | Difference from control | Value for "$t$" | Significance | $P_2O_5$ as % dry wt | Difference from control | Value for "$t$" | Significance | Value of "$t$" for $P$=0.05 | Value of "$t$" for $P$=0.01 |
|---|---|---|---|---|---|---|---|---|---|---|
| A. Control | 0.381 | — | — | — | 0.783 | — | — | | | |
| B. Treated with 10% lead acetate for 2–3 hr | 0.405 | +0.024 | 1.471 | N.S. | 0.813 | +0.030 | 0.698 | N.S. | 2.101 | 2.878 |
| C. Treated with 10% lead acetate overnight | 0.389 | +0.008 | 0.545 | N.S. | 0.759 | —0.024 | 0.523 | N.S. | | |

TABLE III. Effect of lead acetate treatment on the $P_2O_5$ content of roots of barley grown in soil. Means of 12 replicates

| Treatment | Mean $P_2O_5$ content in mg | Difference from control | Value for "$t$" | Significance | $P_2O_5$ as % dry wt | Difference from control | Value for "$t$" | Significance | Value of "$t$" for $P$=0.05 | Value of "$t$" for $P$=0.01 |
|---|---|---|---|---|---|---|---|---|---|---|
| A. Control | 4.150 | — | — | — | 3.626 | — | — | — | | |
| B. Treated with 10% lead acetate for 2–3 hr | 3.950 | —0.200 | 1.198 | N.S. | 3.731 | +0.105 | 0.625 | N.S. | 2.074 | 2.819 |

and grown for three weeks. Thirty uniform plants were then selected and given one of the following treatments:

A. Washed according to a standard procedure [1]).

B. 10% solution of commercial lead acetate added to the soil until leachings appeared. 3 hr later the plants were washed as in A.

C. As in B but allowed to stand overnight (18 hr approximately) before washing.

Ten tomato plants were used for each treatment. The roots from each plant were detached, dried, weighed and digested with mixed acids. The plants that had been treated with lead acetate overnight wilted badly the next day. Considerable amounts of lead had been absorbed by the roots but this was precipitated as lead sulphate during the digestion procedure and was filtered. The analytical results, together with tests of significance, are given in Table II. Lead acetate treatment had no significant effect on either the total P-content of roots or on the percentage of total P in dry matter.

*Barley*

Barley seeds were sown in soil in 6″ pots and after germination reduced to nine seedlings per pot. Twenty five days after germination the plants were given one of the following treatments:

A. Washed according to a standard procedure [1]).

B. 10% solution of commercial lead acetate added to the soil as for tomato and allowed to stand 3 hr prior to washing as in A.

Twelve pots were used for each treatment, and the seedlings from each pot were treated as a unit. After washing, the roots were treated as for tomato.

The results, together with tests of significance, are given in Table III. Lead acetate soil treatment had no significant effect on the P-content of roots as compared with non-treated plants.

From the soil experiments we were not able to determine any loss of P which may have occurred as a result of washing, but as there was no significant difference in the P-content of treated and untreated roots we concluded that the lead acetate soil treatment was not required under our experimental conditions. The suggestion by Russell and Adams [4]) that the value of the lead acetate treatment depends on the efficiency of root recovery, including minimum of mechanical injury, is difficult to reconcile with our data

which show no loss of phosphate during extensive washing of roots of plants, grown in water culture, where root injury did not occur. Moreover in our soil experiments the washing technique used to remove soil from roots was devised by us to give the minimum of root injury.

It is noteworthy that Russell and Adams [4]) cut the tops of the plants at ground level prior to lead treatment of the soil and sampled the roots 24 hr later, whereas we did not detach the tops until the roots were sampled. It is well known that cut stems exude appreciable quantities of sap [3]). It may well be that the difference between the P-content of treated and non-treated roots observed by Russell and Adams [4]) is due to the greater exudation of phosphate from the cut stems not given lead acetate.

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